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Cooperation and entry induction as an extension of technological rivalry ☆

Bruce Kogut *,[a], Gordon Walker [b,†], Dong-Jae Kim [‡]

[a] SH-DH 2000, Wharton School, Philadelphia, PA 19104, USA

[b] School of Organization and Management, Yale University, New Haven, CT 06520, USA

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Abstract

This paper investigates how the structure of cooperation in an industry influences the dynamics of entry by start-up firms. Competition over technological dominance induces the entry of start-up firms into new subfields as incumbent firms seek to expand the consumer base using their technology. By cooperating, incumbent firms succeed to varying degrees in establishing their technologies as a dominant standard by building central positions in a cooperative network. Start-ups tend to enter, however, if there is reasonable certainty that a dominant technology has been established. We find strong support for the relationship between network centrality, as a measure of technological dominance of a standard, and the entry of start-up firms into the semiconductor industry.

1. Introduction

Why should rivalry among incumbent firms encourage entry? A prevailing view of entry into an industry is that incumbents and entrants are adversaries. The contention that rivalry should make entry less attractive is widely held in industrial economics, though whether entry is foreclosed by the construction of entry barriers or by the greater efficiency of incumbents is in question [50]. In this adversarial view, entry is either deterred or accommodated, but it is not welcomed [52].

However, in many industries, the presence of externalities transforms this adversarial relationship into a cooperative network of firms which benefit, at times, from new entrants. As discussed by Hagedoorn and Schakenraad [27], industries such as information technologies display a striking pattern of clusters of firms which have entered into cooperative alliances. [1] These alliances define a network of firms which cooperate and compete with one another. Often, these alliances are expressions of a technological system which embraces multiple firms. For example, the competition between alternative power systems in the late nineteenth and early twentieth centuries, especially between AC and DC, led to a prolifera-

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* Corresponding author.

† Current address: Edwin L. Cox School of Business, Southern Methodist University, Dallas, TX 7525-0333, USA.

‡ Current address: Department of Business Administration, University of Illinois, Champaign, IL, USA.

[1] See also Nohria and Garcia-Pont [43], and Garcia-Pont and Lessard [23].

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tion of alliances among firms before governments mandated a standard. [2] In some industries, alliances occur for non-technological reasons, such as for marketing and distribution access which plays the fundamental role in the biotechnology industry [49].

In industries characterized by competing technological systems, alliances are more than just a mechanism by which externalities are governed. They are also reflections of strategies designed to encourage the entry of firms using compatible technologies. Cooperative alliances are outcomes of the competitive conditions in an industry and serve as a way by which to expand positive externalities among allied firms.

The analysis below seeks to understand cooperation in the context of the competitive dynam-

that rivalry among industry incumbents for technological dominance induces the entry of start-up firms. The empirical investigation focuses on the determinants of entry of start-ups into semiconductor subfields in which incumbents and start-ups both compete and cooperate.

Subfields represent the branching of an industry into distinct markets for specialized technologies related to those of incumbent firms [40]. In the semiconductor industry, subfields have emerged with products that represent a technological evolution from the original use of integrated circuits as a way of densely packing transistors. In particular, standardization requirements for the use of microprocessors have generated competing technological systems. A primary aspect of competition among the dominant microprocessor producers (e.g. Intel, Motorola, and National Semiconductor) is the acquisition of a large installed based in order to gain from customers' desires to buy systems which are widely compatible across users.

The development of subfields in high-technology industries often is driven by the efforts of entrepreneurs who introduce new products and technologies tailored to specialized markets. Entrepreneurial activity fills the gap created by the inability of incumbents to exhaust all innovative possibilities and to fill all niche opportunities. Empirical studies show that small firm entry is promoted in industries where innovation rates are high; overall, small firms introduce 2.38 more innovations per employee than larger firms [1,4]. Bound et al. [6] found that small firms hold a greater percentage of patents than their share of sales. (See also Scherer [45].

A common interpretation of these results is that small firms are more productive in their R&D activities. But these results also suggest that the R&D activities of incumbent firms complement the innovative activities of smaller companies. [3] Incumbents, which are usually large in

activities of other firms to develop specialized and complementary technologies and market niches. Frequently, these other firms are entrepreneurial start-ups.

Complementarity between incumbent and start-up products leads often to adopting common design standards to assure compatibility. Because compatibility among products may be desired by consumers or may reduce the costs of production of existing products, incumbent firms will compete to establish their technology as a standard in the industry. One way to achieve this goal is to share this technology with start-up firms. When the standards for product compatibility are proprietary, they are transferred to a new entrant usually through an interfirm relationship, such as licensing or a joint venture.

As a result, competition over technological dominance by incumbents leads to rivalry over establishing central positions in a network of inter-firm relationships. As a central position is achieved, it encourages entry by providing bene-

[2] The proliferation of alliances among firms in the power generation industry led Hughes [32] to entitle his seminal study *Networks of Power*. See also Wilkins [54] for a discussion of General Electric's international agreements.

[3] For qualitative and statistical studies supporting this interpretation, see Peck and Tamura [44], Mowery and Rosenberg [41], Mansfield [39], Fruen [22] and Clark, Chew and Fujimoto [9] for discussions of technological assimilation across firm and country borders in Japan; Grabher [25] and Herrigel [31] for a discussion of Austria and Germany.

fits for adopting the dominant standard. In this sense, the structure of the cooperative network influences the rate of entry.

In the empirical analysis below, we investigate the effect of the degree of a central firm in a cooperative network on start-up entry into subfields in the semiconductor industry from 1979 to 1989. The results show strong support for the influence of network structure and suggest a new perspective on start-up entry into an industry with competing technologies: entry by start-ups is induced by the rivalry of incumbents for technological dominance.

2. Technological rivalry and entry induction

Competition over standards and technological dominance is a common aspect of new industries and the subsequent development of subfields. Subfield products must often be compatible with the design of products in the basic market. This compatibility invariably entails adherence to a common design standard. Industries undergoing technological change frequently do not have a dominant product design. Anderson and Tushman [2] call such a phase an "era of ferment" during which multiple standards for product compatibility coexist. During such a period, incumbents may compete over the share of product sales compatible to their proprietary standards if there is an advantage to being dominant in the market [13].

An important origin of such an advantage is what is called "network externalities". By network externalities, it is meant that there is a positive return to scale to an installed technology [18], or positive consumption externalities among consumers using complementary products [35]. An example of the former is an electrical grid; of the latter, a software language. [4] Thus, new entrants to a subfield receive a benefit from adopting a widely diffused standard and at the same time increase the benefits for other adopters through enlarging the standard's installed base of customers.

It is the existence of network externalities that makes it advantageous for an incumbent firm to establish its technology as dominant. But three other conditions are also required for competition over technological dominance to take place: proprietary ownership of standards, uncertainty over which standard will eventually dominate the industry, and switching costs. Standards may be public or proprietary. In many industries, public standards are set by professional and governmental institutions or may be adopted freely by observation; in such cases, a standard is a public good. When standards are proprietary, however, the only way a firm can gain access to the standard is through a contractual relationship with the standard's owner or a second source sanctioned by the owner. Furthermore, in the absence of uncertainty over which standard will become dominant, firms in the industry know which standard will be best and will choose only it [17]. Finally, since switching costs make it difficult for consumers to change to a different standard, competition in the early history of an industry is all the more fierce. Once having adopted a standard, users tend to be "locked-in" to purchasing compatible products, even if the standard should prove to be inferior to alternatives [3].

In the absence of a government mandate or other forms of coercion, technological dominance is achieved by capturing as large a share of the market as possible. The interesting implication of network externalities is that the dominant firm benefits not only from its own market share, but by the shares held by firms producing compatible products. It is, consequently, in an incumbent firm's interest to transfer its technology to firms willing to extend the standard to current and new product markets.

These technology-based relationships between firms participating in an industry subfield form a bents may achieve central positions in this network, each central organization linking many other firms together. Centrality indicates, therefore, the degree to which a firm has succeeded in developing a dominant position in the overall network of inter-firm relationships.

Our fundamental contention is that more start-ups are likely to enter a network with a centralized structure which falls short of monopoly. A centralized structure signals to the potential entrant that by joining the dominant standard, it will enjoy a large and growing installed base of customers. Moreover, because of switching costs, the establishment of a central position is likely to endure, decreasing the uncertainty over choosing the "right" design standard for product compatibility.

Fig. 1 provides a schema of the above argument. We focus our empirical analysis on testing the relationship between centrality and entry. Because we have no extensive information on the installed base itself, we cannot test at this time the structural relationships between competition among competing standards in the market to alliance formation and entry patterns. In the discussion, however, we return to the wider evidence regarding the fundamental rivalry in these subfields.

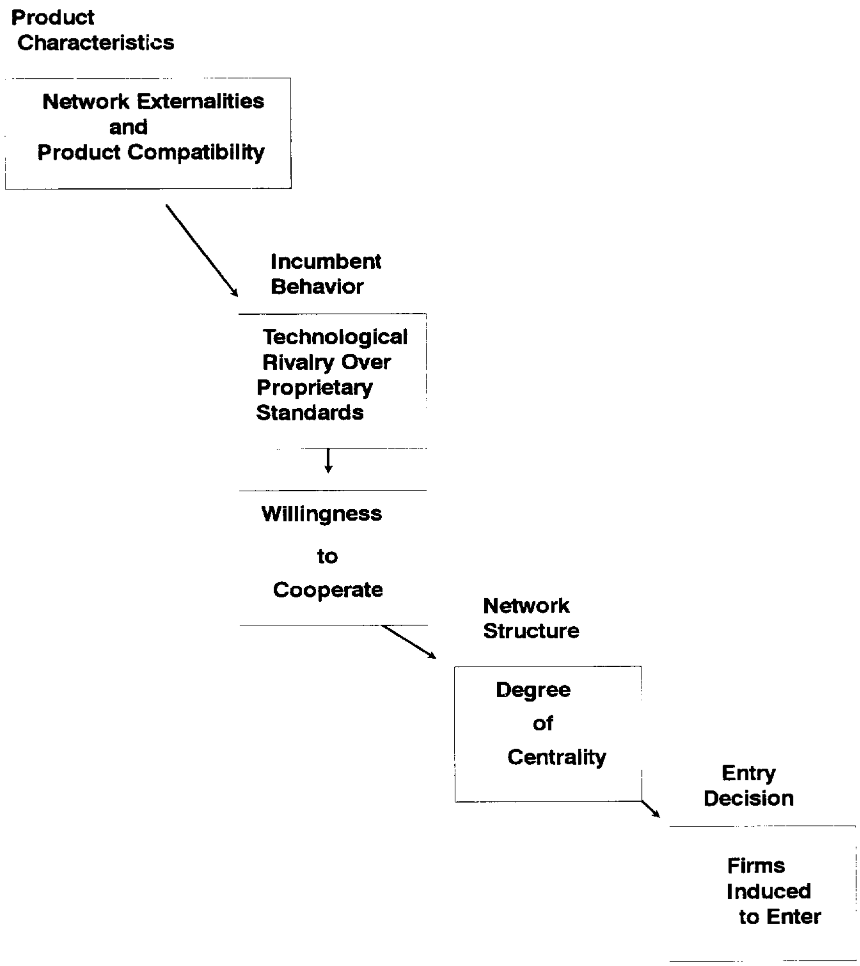


Fig. 1. Schematic representation of causal relationships.

3. Network centrality and technological dominance

An incumbent firm's degree of technological dominance in a subfield is indicated by its centrality in the network of technology-based interfirm relationships. We use Freeman's [21] concept of "betweenness" as the definition of centrality of a firm. [5] According to this definition, an organization's centrality is determined by how many other organizations it ties together that otherwise would have little or no connection with each other, controlling for the size of the network. (See the methods section for a technical description). When the relationships are technology–based, a central firm links together organizations whose technologies are compatible with its own. The larger a standard owner s subnetwork, the more central the firm is and the stronger its position in competition with other firms.

Betweenness has two distinct advantages for measuring technological dominance and its relationship to start-up entry. First, betweenness assigns a centrality value of zero to firms in two types of network where no member is dominant. The first type of network is composed of dyads that are unconnected to each other (see Fig. 2(a)). [6] In this case, there are as many standards for product compatibility as there are pairs of firms. If there are no positive returns to scale in compatibility, this structure may well endure. Otherwise, as new firms enter the market, they will be attracted by incumbents whose centrality rises with the formation of their subnetworks. The second type of network in which no firm is central is composed of firms which are all related to each other (see Fig. 2(b)). In this network, no firm is dominant. Firms have been unable to protect the uniqueness of their technologies and yet relationships are needed to maintain the standard.

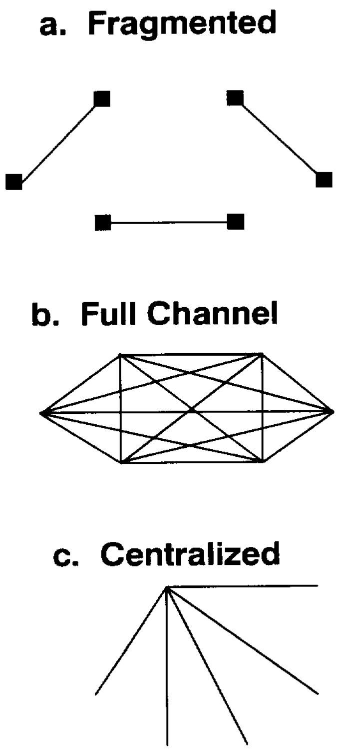


Fig. 2. Types of network structure.

The second advantage of betweenness is that it can be used to form a measure of overall network centrality. This measure, as defined in the methods section below, is defined as the difference between the degree of centrality of the most central firm and the centrality scores of the other firms in the network. Network centrality is obviously zero for the fragmented and "full channel" networks discussed above. [7] The measure rises as one firm establishes a dominant subnetwork and

[5] Hagedoorn and Schakenraad's [27] measure for centrality, which we use below to construct the variable "network density", is the number of alliances over all potential alliance partners. The Freeman measure [21] incorporates higher-order relationships, such as the centrality of a firm regarding not only its licensees, but also its sub-licensees.

[6] It should be obvious that a more extreme case of decentralization exists, viz. a network of isolates. Here we are primarily interested in firms that cooperate.

[7] A network where all firms are connected as a "wheel" would also have zero network centrality. In this case, however, each firm has the same non-zero centrality score. We exclude this structure from our argument since it implies that start-ups and incumbents are equally capable of initiating standards, a possibility that is not consistent with the problem we investigate.

reaches the value of one for a network in which one firm alone connects all other organizations which are otherwise unconnected (see Fig. 2(c)). Thus, network centrality indicates how much more central the dominant firm is than other firms in the network.

4. Network centrality and entry induction

In a period of industry formation, one predictor of a standard's installed base is the size of the subnetwork of firms connected technologically to the standard's owner. A larger subnetwork means both more potential partners and more potential customers using the standard. Since the market for a start-up's product is determined by the market of the standard it has chosen, start-ups should be attracted to firms whose standard dominates the network. Moreover, due to the difficulty of switching standards and the attractiveness of a large installed base, the current size of a standard's market is likely to predict its future size. Given uncertainty over which standard will prevail, network centralization should induce start-up entry. Our primary hypothesis is:

The more centralized is the subfield network, the more start-ups should enter the subfield in the subsequent time period.

5. The density of cooperation and start-up entry

Another argument as to why incumbents enter into relationships with start-ups focuses more simply on the sale of services. Start-ups in subfields typically are not able to perform all activities required to commercialize their products. Frequently they rely on incumbents for product development, manufacturing and marketing expertise. Thus, as Freeman [20] has noted, start-up companies seek "protective alliances" with incumbents in order to enhance their chances for survival and growth. Incumbents in turn gain from cooperation with start-ups by selling services to them and gaining knowledge about their research. In this view, a higher frequency of cooperation in a subfield signals to potential entrants a greater likelihood that they will find partners to provide the services they need.

The density of interfirm relationships in the network represents the ratio of actual to potential cooperation. Higher density of relationships in the subfield reflects a greater willingness by incumbents to cooperate. They are also more likely to be experienced in forming technology-based relationships. When the density of relationships is high, start-ups have a greater chance to find firms with which they can cooperate. In this view, entry is positively related to the number of alliances, but not to the prevalence of network externalities associated with a particular standard. This argument, which does not exclude the effect of network centrality on entry, suggests the following hypothesis:

Higher density of cooperation in the subfield should lead to more start-up entrants in the subsequent time period.

6. Control variables

To control for extraneous effects, we include in the regressions three conventional variables in studies on entry into new markets. [8] By standard arguments in industrial economics, dominant firms in concentrated subfields may deter entry because they have achieved scale efficiencies in operations or controlled critical resources, such as distribution channels or brand equity, that entrants are unable to match. As a number of studies have found, growing industries are attractive to potential entrants. In these industries, new entrants do not have to displace sales from incumbents and overall profitability is likely to be greater. Entry is also likely to be attracted to industries with large demand. We expect, therefore, entry to be positively related to industry size (measured by shipments) and sales growth; negatively related to concentration.

[8] For a summary, see Kogut and Chang [37].

7. Data and method

7.1. Data sources

The main source of the data is Dataquest, a market research firm based in San Jose, California, whose data on start-up companies has been used in previous studies on semiconductors [5,15,47]. Industry data for aggregate sales, number of producers, incumbent strategic alliances, and company sales were retrieved from unpublished or proprietary records. Entry and strategic alliances data of start-up companies are reported by Dataquest [11,12]. The data on strategic alliances were supplemented by studies by Electronics Industries Association of Japan [16] and by Haklisch and Pouletty [28]. Data on interfirm agreements from these two sources were matched against the Dataquest listings, with duplications being eliminated. Several types of interfirm agreement are included: joint venture, licensing, equity (minority) investment, second sourcing, manufacturing, technology exchange, marketing, and research and development.

An entry is recorded whenever a start-up enters a subfield. All first time entries were listed in the Dataquest reports. Of the 126 start-ups for which we had complete data, 35 have products in more than one subfield. Only three of these 35 firms entered two subfields in the same year. To identify dates of entry at the subfield level by multiproduct firms, we had direct telephone interviews with 15 firms for which data were missing. Between 1977 and 1989, a total of 205 entries were recorded. We could not identify six entry dates. Gallium arsenide firms had data for only between 1984 and 1988. Also, we did not have sales data for 1977 and 1978 for the other six subfields. Therefore, we test our hypotheses on seven subfields: analog, ASIC, discrete, memory, microcomponents, and optoelectronics for 1979 through 1989 and gallium arsenide for 1984 through 1988.

7.2. Descriptive patterns of entry and alliances

Before turning to measurement and method, it is instructive to get a sense of the data by looking at a few patterns over time. From outside sources, we know that the evolution of the semiconductor industry has displayed a cyclical pattern of entry. The first great burst of entrants occurred in the 1950s and 1960s following the invention of the transistor and, later, of the integrated circuit [42]. As noted by Brittain and Freeman [8], the dominant firms in vacuum tubes failed to extend their positions in these new technologies. Rather, the start-up companies, e.g. Fairchild and Texas In-

Table 1
Product segments in the subfields

Subfield	Product segments
Analog	Operational amplifiers, comparators, data conversion products, interface products, voltage regulators, and sensors
ASICs	Gate arrays, cell libraries, and programmable 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 [a] Only six start-ups in our sample produce microprocessors, which should be distinguished from those of incumbents, e.g. Intel, Motorola, and National. The start-up companies focus on RISC and other specialized microprocessors.

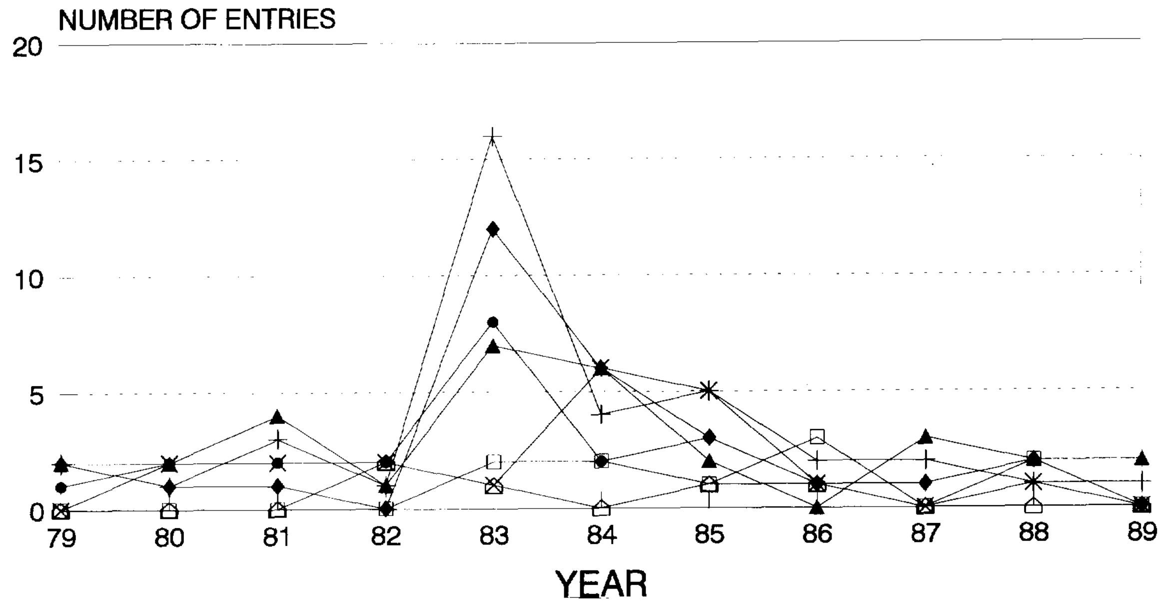
struments, expanded rapidly through the creation and adoption of new process and product innovations.

New start-up entries in the United States industry were greatly curtailed in the 1960s and early 1970s [12]. However, due to the creation of the microprocessor in the early 1970s by Intel and the increasing use of dynamic RAM devices in the computer industry, the emphasis of the industry shifted radically towards the development of digital technologies suited to the growing computer industry.

In late 1970s through early 1980s, new markets arose for more specialized products, e.g. application specific integrated circuits, digital signal processors, and telecommunication integrated circuits. In the United States, these new opportunities led to another wave of the start-up entries. To a lesser extent, start-ups also were founded in Europe, Japan, and in other Asian countries. The data we have collected focuses on this second wave of start-up activities. Table 1 describes the product segments in each subfield of the semiconductor industry.

Many start-ups entering these subfields were initially only design centres; that is, they created new semiconductor products but contracted the manufacturing out to established firms or to specialized foundries. (A foundry carries out manufacturing of the semiconductor.) Thus, even while scale economies were dramatically increasing in manufacturing, small firms could enter by simply contracting out this function.

Moreover, in several of the new subfields, important complementarities exist between subfield products and microprocessors. For example, some semiconductor microcomponents increase the access time of microprocessors. But in order to customize these products and sell them without violating patents, start-ups require access to the microprocessor technology. At the same time, the established firms with proprietary microprocessor technology, e.g., Intel, Motorola, National Semiconductor, desire to make their designs dominant, knowing that customers will be attracted to industry standards in order to avoid the problems of incompatibility in computer hardware. These firms also may have recognized that alliances



would harness the R&D productivity of smaller firms. As a result, both start-ups and incumbent firms in the microcomponent subfield have incentives to cooperate.

Similar conditions exist in ASICs (application specific integrated circuits) and memory. ASICs are customized semiconductors that perform special functions. Very often, they are manufactured directly to meet the needs of an individual customer in conjunction with a specific microprocessor. Thus, cooperation between ASIC vendors and established companies again is promoted.

The need for such cooperation appears less obvious in the case of memory devices. DRAMs, for example, are mass produced semiconductors that can be installed directly in the memory boards of computers. But many kinds of memory devices, such as static RAMS and some kinds of DRAMs work in conjunction with other componentry again require cooperation from established firms in order to acquire proprietary knowledge and legal rights. The compatibility requirements of the other subfields are less evident. Analog semiconductors were initially used in products, e.g. amplifiers, where compatibility requirements were weak. The rising demand of telecommunication integrated circuits, beginning in the early to mid 1980s, led to applications of analog technology in more product areas. Analog products are increasingly used in "system" products, e.g. telecommunications equipment. Standards for compatibility commonly can be accessed through public sources (e.g. complying with regulated transmission frequencies). Some proprietary technologies have been developed for analog products, but competition to make these designs dominant has not been apparent.

Discrete semiconductor products raise few compatibility problems. There is no obvious set of proprietary standards in this subfield. Gallium arsenide is a material that substitutes for silicon; by itself (that is, in isolation from the etched circuitry), gallium arsenide does not rely on technological complementarities. Finally, the optoelectronics subfield is an extension of discrete semiconductors [12,53]. No proprietary design standards are evident in this subfield.

In Fig. 3, the pattern of start-up entry in these seven subfields is graphed. (The sources for the data are described below.) Unfortunately, the

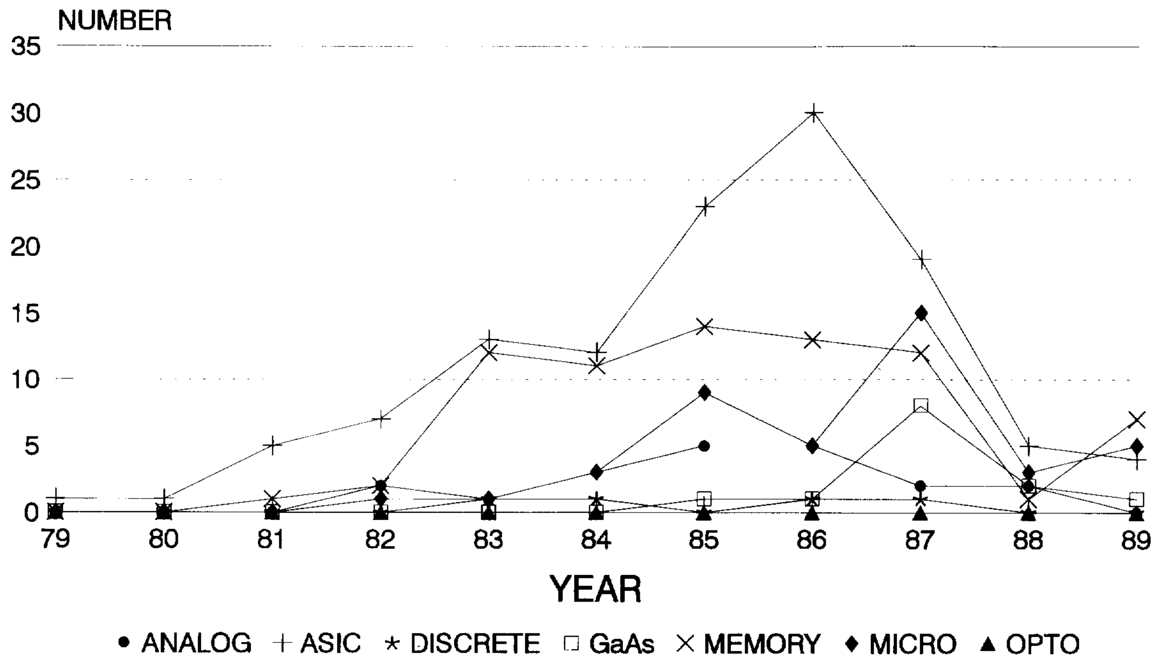


Fig. 4. Number of alliances. *Sources*: Dataquest, EIAJ, and NYU.

time series for some of the products are not complete, as their sales were not sufficiently large to be recorded until recently. Four subfields, ASICs, microcomponents, memory and analog, have a strong mode in 1983. Entry in all subfields appears to steady at zero or a low rate as the decade ends.

Fig. 4 shows the pattern of agreements in the subfields. Note that the modes differ over subfields. ASICs has the greatest number of alliances, and its mode is in 1986. The mode for the memory subfield is 1985, and microcomponent's mode is 1987. A comparison of Figs. 3 and 4 might suggest that the formation of cooperative agreements lags entry by several years. This is not the case, however. The average length of time for the start-ups in our study to form their first interfirm agreement was 1.44 years since their foundings. The modal year is the year of entry with a sharp decline afterwards.

The frequencies of these types for the relationship are shown in Fig. 5. As can be seen, R&D related alliances are the most common. The study by Shan [49] has shown that marketing and distribution alliances predominant in biotechnology. As standards are not an issue in biotechnology, the prevalence of R&D agreements in semiconductors reflects the importance of technology and standardization in this industry.

8. Measures

8.1. Measuring network centrality and network density

Freeman's [21] measure of centrality, called "betweenness," captures the extent to which a firm connects other firms to each other. The measure is computed as a ratio of geodesics. A geodesic between two network members is a path connecting them which has the smallest number of links. There may be a number of geodesics, all of which have the same number of links. The centrality of a point, p, which denotes the position of firm k in the network, is calculated as:

$$C_B(P_k) = \sum_{i<j}^{n} \frac{g_{ij}(P_k)}{g_{ij}} \quad (1)$$

where $g_{ij}(p_k)$ is the number of geodesics between firms i and j which contain firm k and g_{ij} is the total number of geodesics between firms i and j.

The maximum value $C_B(P_k)$ can achieve is $1/2(n^2 - 3n + 2)$ in a network with n members. Since it is desirable to normalize the centrality of a network member by the number of potential partners it can have, Freeman created a normal-

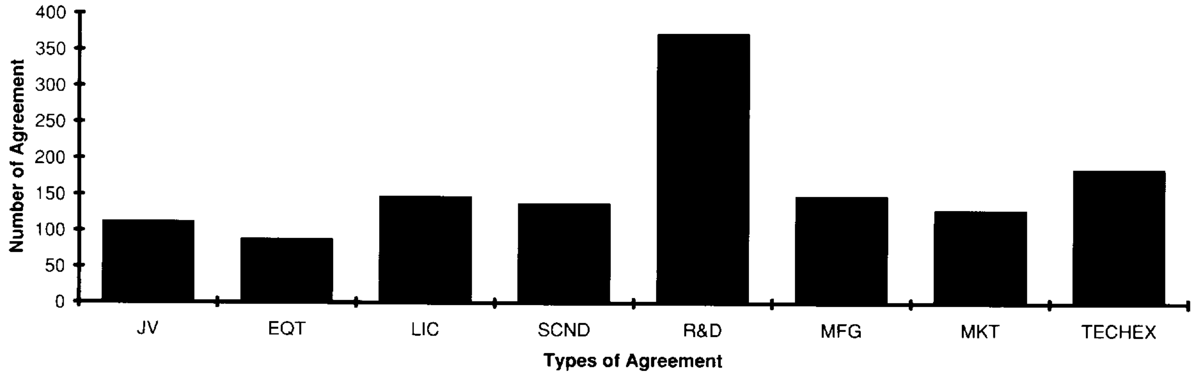


Fig. 5. Types of interfirm agreement (1980–1989). *Sources*: Dataquest, NYU, and EIAJ.

ized measure of centrality using the maximum value. This normalized measure is:

$$C_R(P_k) = \frac{2C_B(p_k)}{n^2 - 3n + 2} \qquad (2)$$

The measure of network (or graph) centrality is, then:

$$C_N = \frac{\sum_{i=1}^{n} \left[C_R(p^*) - C_R(p^i) \right]}{n - 1} \qquad (3)$$

where C_N indicates the degree of network centrality (hereafter network centrality; $C_R(p^*)$ is the centrality of the most central firm in the network; $C_R(p^i)$ is the centrality of the ith firm in the network; and n is the number of firms in the network.

This measure takes on its maximum value when the network is a star or wheel (see Fig. 2(c)), where $C_R(p^*)$ is equal to the denominator in Eq. (3) and $C_R(p_i)$ is equal to 0 for other firms. Thus, the higher network centrality, the more the most central firm acts as a powerful hub connecting all other firms in the network. The lower the network centrality, the less dominant is the most central firm's position, since other firms can connect with each other without relying on it. In this way, higher network centrality represents a more hierarchical pattern of cooperation.

For the purposes of the present study, the continuous measure of network centrality only has meaning for a subfield whose products rely on proprietary standards for compatibility. If standards for compatibility are not proprietary, then firms are not likely to invest in interorganizational relationships to gain access to a standard. Therefore, there should be no reason to calculate a firm's centrality and predict its relationship with start-up entry.

The technical literature and field research produced strong evidence that proprietary design standards with network externalities were important for three subfields, ASICs, microcomponents and memory. However, neither a search of the engineering literature nor interviews with industry experts produced any evidence that the four remaining subfields, analog, discrete, gallium arsenide and optoelectronics, require broad adherence to proprietary standards of compatibility. [7] Where subfield products must be compatible, either the standard for compatibility is "open" and can be accessed from public sources (e.g. transmission frequencies) or it is idiosyncratic to only one or a few applications. It is not surprising, therefore, that the average numbers of cooperative relationships for start-up entrants into each these four subfields were less than one third of the averages for start-ups in the ASIC, memory and microcomponent subfields over the ten year period.

Network centrality for the ASIC, microcomponents and memory subfields was calculated for each subfield separately in each year from 1979 to 1988. The network for a subfield was constructed by including all *technology-based* relationships existing in a year between firms, start-up or incumbent, that participated in the subfield and their partners. Technology-based relationships were defined as licensing relationships, joint ventures that included technology transfer, second sourcing agreements, manufacturing agreements, and agreements that involved product development or design.

In these three subfields, start-ups were typically outnumbered by about two to one by incumbents among which were included the incumbents most central in the network. That is, the most central firms also sold products in the subfield. The subfield network thus included not only standard owners (e.g. Intel) but those firms to whom they had licensed their technology as second sources (e.g. Advanced Micro Devices).

Given the absence of proprietary technologies with network externalities in the four other subfields, an estimate of network centrality would reflect only the fragmented structure of idiosyncratic relationships. Furthermore, the number of alliances per start-up in these subfields is low, consistent with our observation that design standards are not important. Their networks are therefore composed primarily of idiosyncratic re-

[7] See Kim (forthcoming) [36] for details.

lationships between incumbents. Without significant externalities in these subfields, the structures of their networks, as opposed to their densities (see below), in theory do not provide start-ups with a benefit. Consequently, we followed the arguments relating technological dominance and network structure reflected in Fig. 2 and set the network centrality scores for these four subfields to zero.

We control in two ways for the potential effect this constraint may have on the tests of the influence of network centrality on start-up entry. First, we test the effect of network centrality only on data from the ASIC, microcomponent and memory subfields and compare these results to those from tests on all subfields. Second, we include dummy variables for the subfields in regressions using the full data set.

Although differences among subfields regarding the existence of proprietary standards and network externalities affect the measurement of network centrality, these differences clearly do not influence the measurement of the density of cooperation (hereafter network density). For all seven subfields, network density is measured by dividing the count of agreements by the number of possible agreements in the subfield. (We normalize the simple count in order to avoid a bias due to differences in the number of entrants among subfields.) Since we code agreements as symmetric, the maximum number of agreements among N firms in a subfield is N(N – 1)/2. In contrast to the types of relationships used to construct the network to measure centrality, we use all types of interfirm agreement, including marketing agreements, to calculate network density for each subfield. Network density was calculated for a subfield for each year from 1979 to 1988.

8.2. Other variables

The dependent variable (entry) is the number of entries into a subfield for a given year. The date of entry into an industry subfield was identified by the year when the start-up firm began producing the product. As entry is conditional on the observed characteristics of the industry, the independent variables were lagged one year, as specified in our hypotheses.

The size of a subfield in sales is measured by the variable shipment, which represents the subfield's total shipments (i.e. sales volume) in a year. Sales growth is the annual growth of each subfield in terms of aggregate sales. Concentration is measured for each subfield in each year by calculating the Herfindahl index.

8.3. Model specification

We stacked the cross-section panels, generating 66 observations on entries into these subfields. The unit of analysis is the entry count for the subfield/year. Because the dependent variable is a count, a Poisson regression is used to model the probability that the number of entries will occur n times (with $n = 0, 1, 2, \dots$) as follows:

$$\mathrm{Prob}(Y = y_j) = \frac{e^{-\lambda_j}\lambda_j^{Y_j}}{Y_j!} \tag{4}$$

with Y_j being the count of relationships for the jth firm. To incorporate exogenous variables, λ can be made a function of the covariates:

$$\lambda_j = \exp\left(\sum B_j X_{ij}\right) \tag{5}$$

where B's are the coefficients, X's are the covariates (with X_1 set to one), i indicates the ith variable, and j is the jth industry. The exponential function ensures non-negativity.

The Poisson distribution stipulates that the mean and variance are equal. It is not uncommon in social science data that the variance should be greater than the mean owing to unobserved heterogeneity in the sample. To allow for overdispersion, we estimate heterogeneity by specifying a compound distribution through an addition of an error term. Equation 5 now becomes:

$$\lambda_j = \exp\left(\sum B_j X_{ij}\right) \exp(u_j) \tag{6}$$

λ is no longer determined but is itself a random variable. As u_j is unobserved, it is integrated out of the expression by specifying a gamma distribution, whereupon the now compound Poisson reduces to the negative binomial model

[33,29] [8]. Given this specification, an additional parameter, labelled a, is estimated in the regression; it provides a measure of contribution of heterogeneity caused by omitted variables. For some of the regressions, overdispersion was rejected and, consequently, only the Poisson estimates are shown for these runs. In addition to the subfield dummy variables, we also included a dummy variable for each year to test for structural biases.

9. Results

In Tables 2 and 3, the correlations and means are reported. Because of the somewhat high correlations between network centrality with network density and concentration, we estimate the regressions below with and without these variables.

Table 4 gives the results for the negative binomial regressions. Because network centrality is more than moderately correlated with network density and concentration, we test for their effects separately and together in columns 1, 2 and 3. The results show that network centrality has a significant effect on start-up entry whether or not network density and concentration are controlled for. Thus, the primary hypothesis that higher centrality will encourage more entry is supported. [9]

In contrast, network density has no effect on entry, whether network centrality is controlled or not. Apparently, it is not the overall availability of partners with whom to cooperate which influences entry. Rather, entry is encouraged in the context of specific network structures. In the case of semiconductors, the mediation by a dominant firm in standard setting is a significant structural determinant of entry. The structure of agreements, because they influence the perception of uncertainty around standards, is a far more important factor in determining entry by new firms than the general propensity to cooperate.

The control variables show little significance. Concentration has a negative influence on entry, when network centrality is included in the equation, but no effect when network centrality is excluded. This result suggests that the effect of concentration on entry is dependent on the level of network centrality. Sales growth has no influence on entry. Shipment, moreover, has a marginal effect which is opposite to the predicted relationship.

It is possible that the estimates are influenced by unobserved subfield and time period effects. To test for the robustness of the results, we ran several additional tests reported in Table 5. Moreover, since we calculated network centrality only for those subfields, ASICs, microcomponents, and memory, in which proprietary standards with network externalities are present, we were particularly concerned about the importance of subfield effects on the estimations. In column 1, the results for the regression using

Table 2
Correlations, means and standard deviations

Variable	Correlation matrix				
Shipment	1.000				
Sales growth	0.201	1.000			
Concentration	−0.002	0.305	1.000		
Network density	0.281	−0.010	0.291	1.000	
Network centrality	0.219	0.328	0.589	0.591	1.000

Table 3
Means and standard deviations

Variable	Mean	Standard deviation
Shipment	4304.2	2998.7
Sales growth	22.000	22.727
Concentration	0.057	0.081
Network density	0.003	0.004
Network centrality	0.212	0.251

[8] Greene's statistical package (LIMDEP) [26] provides this test as a standard feature.

[9] Since there are multiple standards competing for hegemony, each may develop an extensive subnetwork and thus have a relatively central position. In this case, start-ups have a choice among a number of standards, each with a relatively large installed base. We verified the relationship between centrality and entry by regressing entry on the centrality of the top two, three, four, and five firms. All four regressions were consistent with the results reported in Table 4.

Table 4
Negative binomial results: entry as dependent variable

Variable	(1)	(2)	(3)
Constant	1.52 [a]	1.18	1.50
	(0.428)	(0.737)	(0.439)
Shipment	−0.001 [b]	−0.0001	−0.0004
	(0.0005)	(0.0001)	(0.0005)
Sales growth	−0.004	0.562	0.0001
	(0.007)	(0.013)	(0.007)
Concentration	−21.6 [a]	−7.02	21.41 [a]
	(7.55)	(12.16)	(7.45)
Network density	−23.24	81.05	
	(33.43)	(81.25)	
Centrality	3.41 [a]		3.24 [a]
	(0.671)		(0.56)
α	0.182	1.08 [a]	0.209
	(0.150)	(0.37)	(0.148)
Log likelihood	−104.82	−115.42	−104.62

Standard errors in parentheses [a] $P < 0.01$ [b] $P < 0.10$

dummy variables for the three subfields with non-zero centrality measures; the results do not differ from the main results shown in Table 4,

Table 5
Negative binomial results: entry as dependent variable

Variable	(1)	(2)	(3)	(4)
Constant	3.98 [a]	2.43	0.78	0.04
	(1.12)	(1.55)	(0.97)	(0.78)
Shipment	0.0001 [a]	−0.0002 [a]	−0.0002 [b]	0.0001
	(0.00006)	(0.00007)	(0.0008)	(0.0001)
Sales growth	0.002	0.002	0.004	0.007
	(0.007)	(0.007)	(0.007)	(0.007)
Concentration	−73.0 [a]	−54.6 [c]	−16.2 [c]	−13.5 [b]
	(25.36)	(28.9)	(9.26)	(6.28)
Network density	31.0	34.6	10.2	14.1
	(45.89)	(44.0)	(41.7)	(35.3)
Centrality	3.25 [a]	3.50 [a]	4.01 [a]	1.87 [a]
	(1.39)	(1.05)	(1.15)	(0.548)
ASIC	−0.73	–	–	–
	(0.82)			
Memory	1.13	–	–	–
	(0.85)			
Micro	2.13	–	–	–
	(1.51)			
All subfields	–	5.86	–	–
Year dummies	–	–	–	2.96
α	0.132	0.083	0.157	–
	(0.141)	(0.129)	(0.231)	

Table 6
Akaike's Information Criterion Test

Model	3.1	4.1	4.2	4.4
Log likelihood	−104.82	−98.3	−94.6	86.8
Number of parameters	7	10	12	16
AIC value	223.64	216.6	213.2	205.6

column 1. Employing dummies for the subfields (the coefficients are summed and shown jointly) also did not change the estimates, as given in column 2 of Table 5. Column 3 reports similarly robust results for a reduction in the sample when records for the subfields for which we recorded zero centrality values were discarded. Clearly, subfield effects do not decay the robustness of the estimates.

To see if adding subfield and year dummies should contribute explanatory power, we compared our models using Akaike's Information Criterion test (Table 6), which has been widely used to compare nested models [34]. This test consists of comparing the likelihood ratios of models but adds a penalty for adding variables; it does not require that the models be nested. [10] The model is denoted in the first row as to the table and column. The best model is the regression with year dummies (Table 5, column 4), though the models with subfield dummies also improved the Akaike information criterion value over the baseline estimates. There is clearly more information in the time and subfield effects than what is captured by the baseline variables.

10. Discussion

We have predicted start-up entry into subfields by 1) incumbent competition for technological dominance, 2) the prevalence of cooperation in

[10] The models are, in fact, nested, with the questionable exception of column 4 in Table 5 which rejected the negative binomial specification and gives only the Poisson estimates. But since the Poisson specification lies, so to speak, at the

the subfield, 3) product market competition within a subfield, and 4) subfield size and growth rate. The first is captured by network structure, i.e. network centrality; the second by network density; the third by concentration; and the last by shipment and sales growth. The results indicate that of these potential influences, technological and product market competition are the driving forces behind start-up entry. Technological competition, which underlies the centralization of the cooperative network, has the most significant influence. This finding, combined with the absence of any effect on entry by network density, shows that it is the structure, rather than the prevalence, of cooperation that leads to subfield entry. Product market competition, captured by the (lagged) count of firms in a subfield has a small effect.

In our study, start-ups choose the standard with which their products must be compatible and this choice determines who their partners will be. Because start-ups have discretion over the adoption of a standard, they enter in greater numbers when network centrality is high, expecting a larger enduring installed base of customers. As spatial contiguity is not a constraint, it is all the more impressive that a few firms emerge as central actors in the semiconductor industry.

To demonstrate the tendency by start-ups to choose dominant firms as partners, we calculated the mean centrality of firms with which start-ups establish relationships. This value is always above the twenty-fifth percentile and rises over time to within the top 2% of all firms in the network. These central firms are always incumbents. Start-ups clearly target the most central firms which are all large established organizations.

Our explanation of entry induction has assumed that the resources and motivations of start-ups and incumbents differ regarding entry into subfields. To test the reasonableness of this assumption, we ran a regression to see whether our model predicted incumbent entry into subfields. In the results (not shown), no variable predicts incumbent entry. Although we expected the variables measuring cooperation would not influence incumbent entry, it is surprising that the variables measuring competition and subfield size are also poor predictors. A likely explanation is that incumbents enter subfields after having developed substantial capabilities in traditional lines of business. Subfield entry may be more an extension of these capabilities, with barriers to entry in any subfield being of little importance.

11. Firm strategies and technological dominance

Referring back to Fig. 1, it can be seen that our study has concentrated on the relationship between the downstream links in a causal chain. There are two levels of analysis in the question of technological rivalry and start-up entry. We have concentrated on the lower or first level, whereby start-ups mobilize resources to enter subfields in response to network structure. But at a higher or second level, network structure is the result of actions by established firms competing for technological dominance in order to capture externalities. Network centrality is exogenous to the first level analysis and endogenous to the second.

While we cannot explore this more fundamental relationship in a regression context, further insight into our findings can be gained by moving from the statistical tests to examining the identity of central firms, especially Intel, Motorola, and National Semiconductor. While Intel has succeeded in supplying its microprocessor to IBM and its clone market and Motorola, the Apple market, National Semiconductor has failed to tie up a major vendor. Thus, even though all three firms announced a 32-bit microprocessor within roughly a year of each other, National Semiconductor has seen its market share steadily fall over the decade, from 23% in 1986 to 5% in 1988.

As shown in Table 7 below, National Semiconductor has been become the actor with the highest share of agreements in all subfields. [11] A firm's share of agreements picks up its willingness to cooperate, but it hardly is a statement regard-

[11] The relative centralities of Intel, Motorola and National in the microcomponent, ASIC and memory subfield networks are consistent over time with their shares of agreements as shown in Table 7.

Table 7
Selected established companies' alliance shares across all subfields (%) [a]

Year	Intel	Motorola	National	TI	Toshiba
1979	0.00	1.77	1.33	0.00	0.00
1980	0.00	1.87	1.49	0.00	0.37
1981	0.88	2.07	1.48	0.59	0.59
1982	1.81	2.04	1.13	0.90	1.36
1983	2.59	2.10	1.62	0.97	1.29
1984	3.46	2.06	2.81	2.06	1.08
1985	3.46	2.09	2.67	2.02	2.16
1986	2.87	2.01	2.57	1.91	2.41
1987	2.72	1.77	2.97	2.02	2.44
1988	2.50	1.61	3.42	2.39	2.30
1989	2.53	1.65	3.22	2.45	2.24

Sources: Dataquest, EIAJ, and NYU [a] Number of alliances of the firm (cumulative)/total number of alliances (cumulative)×100

ing its performance in the product market. Simply put, Intel and Motorola have been more successful in their relationships than has National Semiconductor because they have succeeded in the final market for computers and other products using their semiconductors; consequently, unlike National Semiconductor, they were not compelled ultimately to establish as extensive a web of cooperation.

These observations point to the historical development of competition. As shown in Fig. 6, network centrality peaks in 1984 and, then, flattens out. In light of the corresponding pattern of low, flat entry, it appears that National Semiconductor's cooperative strategy has at best a marginal ability to induce new start-ups to enter. It is no wonder cooperative agreements also decline in the late 1980s. The dominant positions of Intel and Motorola have, essentially, locked the industry into their standards. Barring new technological developments, there is little cause to suspect that the rate of entry, or of cooperative agreements, will increase again.

These observations suggest that our results are rather sensitive to the particular time period under investigation. In fact, if a firm, such as Intel, should achieve a quasi-monopolistic position in setting standards, its incentives to cooperate and, consequently, to induce entry should certainly decline. Fig. 7 depicts illustratively that the pre-

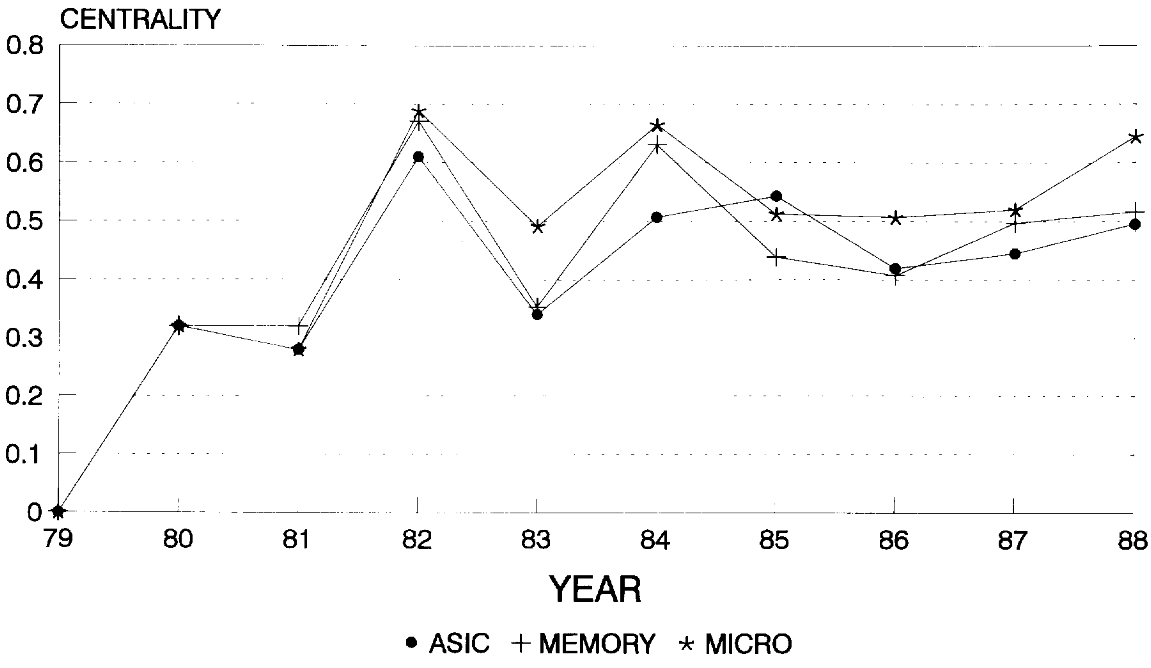


Fig. 6. Network centrality. *Sources*: Dataquest, EIAJ, and NYU.

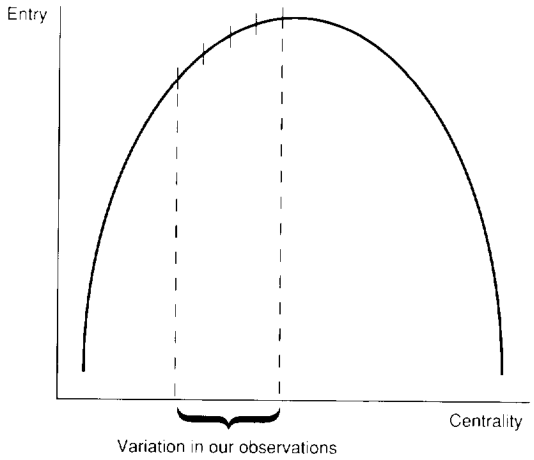


Fig. 7. Relationship of entry and centrality.

sumed relationship between entry and centrality is most likely non-monotonic, with entry induced only in times of competition among a few alternative standards. Too many standards raise the uncertainty over the extent of positive externalities captured by associating with a dominant technology; too few standards diminish the willingness of the dominant firms to cooperate. Given the limitations of a short time series for one industry, our observations are unlikely to be sufficiently varied to capture the non-monotonocity in the relationship between entry and network centrality. [12]

Consequently, our results are likely to apply generally to industries experiencing competition around standards. An interesting possibility is that a sudden technological switch to a different standard could occur if a firm, or association of firms, holding a dominant share of the final market decided to defect. Such a possibility in the area of software lies behind the growth of agreements between several historical competitors in the computer industry (e.g. Apple and IBM), as well as the discussion in Japan over an alternative operating system in development at the University of Tokyo. In Japan, the microprocessor and operating system of NEC has built up a dominant position.

New microprocessor technologies, such as RISC, are interesting because they threaten the viability of the current network of agreements. It is not surprising that the introduction of new technologies-generates not only a new entrants, but also a new wave of cooperation as a form of competition over standards. The determination of which standard, or technological system, prevails is as much a question of the strength of the coalition which a firm builds as the inherent merits of the technology itself.

12. Conclusions

This paper has analysed the effect of subfield network structure on entry of start-ups. The results point consistently to the role large incumbent firms play in choosing to "spill over" their technologies and capabilities to benefit new firms. In the view we put forth, small firms are not only born in response to exogenous technological change, but also are induced by the competitive rivalry among incumbents.

These results offer insight into the studies, on alliances and cooperative networks [e.g. 27] regarding differences over time and across industries. By our argument, alliance activity varies due to changes in the underlying dynamics of an industry. For the case of semiconductors, as uncertainty and competition over technological standards are resolved, alliance activity begins to flatten out. Moreover, the frequency of activity across industries will vary depending on the extent of externalities and rate of innovation.

Our analysis has sought to move the investigation of networks from descriptive comparisons to an outstanding of network formation in terms of the fundamental conditions of industry competition. The dominance of large firms in a network is partly an expression of size. But we know from comparisons to other high technology industries, such as biotechnology, that some networks do not demonstrate the pattern of large firm dominance characterizing the semiconductor industry. The origins for this pattern in semiconductors rests in

[12] The decision by Intel not to license its more advanced microprocessors to traditional licensees, such as AMD, is very likely a reflection of its increased dominance in the industry and the diminution in benefits gained by cooperation.

the strategic benefits for a firm in forcing its technology as the industry standard. Usually, this dominance is achieved by only large firms, though new entrants may succeed in becoming large by the industry acceptance of its technological standards.

If our results have a public policy implication, it is a simple but general one: the health of an industry and economy is the result of balance between cooperation and competition, large and small firms, and innovation and diffusion. [13] Entry, growth, and exit reflect this balance achieved through entrepreneurship of small firms and cumulative knowledge and assets of larger companies. The recommendation consistent with a broad ecological view of organizations cannot be to identify elusively an optimal *firm size*, but to promote an appropriate and dynamic *distribution* of both large and small enterprises.

[13] See the debate between Gilder [24] and Ferguson [19] as an example of falsely stylizing the issue as conflict between small and large firms.

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