BALANCING INTRAPRENEURIAL INNOVATION VS. ENTREPRENEURIAL SPINOFFS DURING PERIODS OF TECHNOLOGICAL FERMENT

Joel West, San José State
Caroline Simard, Anita Borg Institute

ABSTRACT

The period immediately after a technological discontinuity allows an innovative startup to exploit a period of ferment and great uncertainty. Meanwhile, mature innovators must develop intrapraneurial capabilities to compete with these new entrants.

Using multiple data sources, we examine the innovation capabilities of Linkabit, a firm that exploited the opportunities related to digital communications, and how those capabilities were transferred to informal spinoffs which formed at twice the rate of Fairchild Semiconductor. We discuss the contingent value of innovation capabilities for early stages in a technological regime, as well as the conflicting goals of intrapraneurial development vs. restraining entrepreneurial exodus.

INTRODUCTION

Discontinuous technological change enables new innovations and the associated goods and services. Such innovations often render obsolete the advantage of established incumbents, and thus creates entrepreneurial opportunities for new firms. At the same time, incumbents don't voluntarily relinquish their lead to rivals. To cope with such change, a range of both normative and positivist research concludes that incumbents must encourage innovation, individual initiative, flexibility and decentralized authority. Much of the research on incumbent survival has focused on establishing both cultural and structural incentives for intrapraneurial activities. Such intrapraneurship is often modeled on the activities of entrepreneurial startup companies.

Here we consider the discontinuity associated with the shift from analog to digital communications. In the context of this technological discontinuity, we first look at the formation and success of Linkabit Corporation, an entrepreneurial startup that built the necessary capabilities and sought to maintain these capabilities as it grew and matured. We identify the capabilities transferred to 76 direct and indirect spinoffs, and the factors prompting such an exploding seedpod of entrepreneurial formation. From this, we suggest that the capabilities that are a source of competitive advantage in a context of technological discontinuity may no longer yield such advantage in the context of maturing technology and increased competition, and comment on the dilemma of encouraging intrapraneurial initiative without fueling entrepreneurial spinoffs.

RESEARCH DESIGN

Entrepreneurial opportunity comes from the industry change process that Schumpeter (1934) termed "gales of creative destruction." In technology-based industries, the advent of a technological discontinuity can disrupt an existing technological regime, eventually leading to a new regime (Nelson & Winter, 1982; Tushman and Anderson, 1986). The new regime often renders obsolete the competencies of the established incumbents, thus displacing existing firms and creating opportunities for new firms. The period between the discontinuity and the establishment of the new regime is a period of technological ferment, with high uncertainty as both new and existing firms seek to identify which technologies, markets and capabilities will be most valuable in the new regime (Anderson and Tushman, 1990; Utterback, 1994; Tripsas and Gavetti, 2000).

The early (ferment) period of a new technological regime provides the greatest returns to scientific inquiry, based on the ability to solve the Kuhnian puzzles associated with a new trajectory (Dosi, 1982). This is the period of most rapid improvement in product performance, as technologists discover and advance the capabilities of the new regime, and also the period where even incumbents are unlikely to achieve economies of scale due to rapidly changing designs and technologies (Utterback, 1994).

New technologies may allow incumbents to profitably redeploy existing capabilities (Tripsas and Gavetti, 2000). At the same time, the incumbents may have obsolete technological competencies, overestimate their capabilities or underestimate the potential of a new technology (Foster, 1986, Tushman & Anderson 1986). Even for capable firms, innovation becomes more difficult for established firms as they grow and mature (Dougherty & Hardy, 1996; Bantel, 1998). Despite differences in outcomes and firm context, researchers have suggested that successful intrapreneurial activities and attitudes are those that parallel entrepreneurial counterparts in new firms (Zahra, 1994; Sharma & Chrisman, 1999).

The shift from analog to digital communications was such a change. Analog communications had reached its limits by the 1950s, as improvements on one dimension (e.g. adding color to TV broadcasting) led to trade-offs in another (reduced transmission range). The solution had come in the 1940s, when mathematician Claude Shannon invented the basic principles enabling digital communications, but Shannon's principles were impractical to implement until the 1960s brought rapidly improving semiconductor performance (as captured by Moore's Law). Digital communications technologies were initially limited to high-performance, price-insensitive applications such as deep space communications, but eventually enabled mainstream consumer technologies such as modems, CDs, DVDs, GSM cell phones and HDTV.

Here we look at Linkabit Corporation, which was notable for three reasons. First, it was among the first entrepreneurial startups to focus on digital communications, using its innovation capabilities to pioneer a number of key early technologies. Secondly, it transferred those capabilities to more than 70 new startup companies formed by the alumni of Linkabit and its descendants. Finally, those startup companies formed the nucleus of a new geographic cluster of telecommunications companies, with more than 200 wireless communications companies founded in the San Diego region during the period 1980-2000.

We draw upon multiple methods from an ongoing study of wireless telecommunications startups. These include 29 interviews with 27 Linkabit alumni, including 13 alumni that founded a total of 25 telecommunications startups. We supplement this with a database of Linkabit spinoffs, published oral histories of two company founders, company newsletters (*A Bit of News*) from 1979-1986, and recruiting ads published by the company from 1978-1985. We also draw upon an overlapping database of 244 wireless companies formed in the same region as Linkabit.

LINKABIT'S INNOVATION CAPABILITIES

The development of digital communications products was based on the concepts of information theory developed by Claude Shannon, first at AT&T Bell Labs and later as a professor at MIT. Linkabit's initial successes came as its founders and early employees were the first to apply these principles to solve specific communications problems.

Founding

Linkabit was founded in 1968 by three university professors: Irwin Jacobs of the University of California, San Diego, and Andrew Viterbi and Leonard Kleinrock of the University of California, Los Angeles. All held graduate degrees in electrical engineering from MIT. They formed the company to pool their part-time consulting activities in the field of communications engineering, initially as subcontractors for defense firms in the region (Morton 1999a, 1999b). While Kleinrock soon left, after five years Linkabit grew enough for its remaining founders to quit academia to work for the company full time. The company grew rapidly for the next 15 years, until the two left the company over conflict with the new owners (Table 1).

The two founder-managers (Jacobs and Viterbi) had unique credentials to exploit this technological discontinuity. They had become experts in the concepts of information theory, and had published widely used communications textbooks in 1965 and 1966, respectively. Jacobs had studied with Claude Shannon himself and was well known for being at the forefront of the field. Perhaps most significantly, in 1966-67 Viterbi discovered an optimal error correction algorithm for digital encoding — a solution later used in space communications, modems, cell phones and dozens of other cases where a digital signal is encoded and decoded across an analog transmission medium such as a wire or radio signal (Viterbi, 1967; Forney, 2005). Linkabit's first employee renamed this algorithm "Viterbi decoding" to provide an advantage marketing its services to government customers, and, in fact, the company's first major product revenues came from selling such error correcting hardware for a US Army communications satellite (Interview, Jerrold Heller, June 28, 2005).

During the 1970s — a period of technological ferment in digital communications and signal processing — the company stayed at the forefront of the new technology through its understanding of cutting edge theory. As one former employee recalled: "Linkabit was doing digital signal processing and real signal processing that was only being discussed in a couple of text books at MIT and Stanford…And these guys were doing it and this is just hugely like, 'Wow, this is happening here and it's not just happening in books!'" (Interview, Feb. 25, 2004).

In this period, the company's expertise on digital communications was most in demand by the U.S. government and its suppliers for applications where requirements dictated new technology delivering the ultimate in performance — notably space and military communications. Linkabit's revenues came from research projects, technology design and limited-production components and systems, and its advantage came from its ability to provide more powerful or cost-effective solutions than its competitors.

Key Innovation Capabilities

As a startup in the early phases of a technological discontinuity, Linkabit's successes depended on its capabilities for developing and commercializing innovative technologies. Our interview and archival data suggested three key dimensions to these capabilities: technical proficiency, support for creativity and an entrepreneurial orientation.

The first element of the company's innovation capabilities was a high level of engineering excellence based on highly capable workers. As one founder-alumnus said: "The Linkabit culture was one of arrogance and technical superiority. … The technical work was fabulous at Linkabit, there were brilliant people to work with, and it was an unbelievable opportunity" (Interview, Nov. 4, 2003). In particular, the tacit knowledge of digital communications specialists allowed optimization of performance given cost (or vice versa). For example, improved signal/noise performance on a signal processing chip would allow NASA to use smaller radio telescopes for communicating with deep space probes.

The second element was a support for intellectual curiosity that enabled creativity. As documented by subsequent research (e.g., Nohria & Gulati, 1996), innovative firms need an optimal level of slack — enough to allow creativity, but not so much as to divorce those creative pursuits from delivering results benefiting the corporation. Linkabit's academic founders allowed their engineers considerable autonomy to explore interesting ideas — unlike at more hierarchical firms where supervisors tightly controlled which efforts received resources.

Together, these traits created a research culture that former employees likened to a university campus. Jacobs said efforts to replicate a college campus were a conscious attempt to spur innovation:

> A university has a tremendous advantage as far as coming up with ideas, innovations, etc. Namely, you have a new class of students coming in every year,

> and they ask lots of questions, and that's the intent of the university is to ask lots of questions. So you keep everything stirred up.
>
> The question is, in a company, how do you encourage people to ask the questions to keep things stirred up intellectually. And so that was something we always had to be concerned about. (Jacobs, 2005)

However, Linkabit was not the only communications firm to hire creative college graduates. The largest number of telecommunications breakthroughs of the 1960s, 1970s and 1980s were made by AT&T Bell Labs, which hired elite researchers, published a research journal and employed many Ph.D. holding researchers (including Shannon) that were equally at home at Bell Labs or in a university.

A key difference between the two was Linkabit's entrepreneurial, risk-taking approach to spotting and pursuing opportunities, where individuals were encouraged to identify and pursue new business opportunities. Even approaching its 15th birthday and more than 300 employees, Linkabit retained a culture more reminiscent of a Silicon Valley startup than that of the 50-year-old research lab of the world's largest telephone monopoly.

The combination of these three elements — technical excellence, encouraging creativity and an entrepreneurial mindset allowed the firms to identify important problems, apply knowledge of the new technological regime to those problems, and solve those problems in an effective way. One former employee summarizes the company culture: "It was really elite. [Vierbi and Jacobs] just had a cool engineering environment, very macho. It was neat go up hills with them. They were outstanding leaders. A macho, we are so smart attitude, obnoxious to most people. That was the Linkabit experience" *(Interview, April 16, 2004)*

Developing and Reinforcing Capabilities

The company's founders made specific decisions to develop, extend and maintain its innovation capabilities. Their two key strategies were the use of leadership by example, and through recruiting new employees.

Even after a startup grows beyond the personal span of control of the founder(s), their values and attitudes continue to be reflected in the organization's culture. Prior research has shown that the founder-managers of a startup company have a powerful influence on an organization's culture, since they designed the organization's blueprint from its inception (Baron, Hannan and Burton, 1999). Such a culture reflects conscious efforts of the founder entrepreneurs, but also may endure past the company's growth into maturity.

Former employees of Linkabit repeatedly cited the founders' leadership style in keeping engineers focused on innovation and entrepreneurship. One Ph.D. holder (later entrepreneur) emphasized this style in encouraging exploration of new ideas:

> Irwin Jacobs had an intrapreneurial mindset. You could come to him at any time with your ideas, and he never said no…. he would say, 'continue with your job you are doing now cause that's important, but we'll see, maybe we'll fund your idea, keep working on this.' If you say 'nah, we are not interested' you are going to lose good people and replacing them is very hard. If they are good and it's something that turns out OK maybe you'll make money off of it. If you fund it with 50 grand, they are still working for your company, and it can still pay off because they are not competing with you (Interview, January 29, 2004).

The other decision that had a major impact on innovation capabilities was Linkabit's practice of hiring "the best and the brightest." During its high growth period, the company hired aggressively from prestigious electrical engineering programs.

While it actively recruited at some 20 colleges, the school with the greatest impact was MIT, where Jacobs had been a junior professor before leaving for UCSD in 1966. Like the founders, the company's first two employees had graduate EE degrees from MIT. Linkabit also leveraged its alumni employees to hire new MIT graduates, both in making personal visits to campus and by listing alumni employees in its on-campus recruiting ads from 1978-1981. The level of education was less important than the employee's aptitude, as its most successful employees included both Ph.D. holders and those who stopped with a bachelor's.

As with other technology startups, such hiring practices enabled engineering excellence. By recruiting workers when they were still malleable, Linkabit strengthened its ability to inculcate creative and entrepreneurial attitudes among its engineers. As co-founder Andrew Viterbi explained

> I used to say it's best when you get them young, out of school, they haven't learned bad habits. And so I would say that the vast majority of the leaders, the people who developed into leaders at Qualcomm and at Linkabit were people that we got virtually straight out of school. … [The key was] you give them freedom to develop (interview, June 15, 2004).

Innovation Successes

Linkabit was a comparatively small company, building on the basic research developed by AT&T and other defense and civilian manufacturers. However, Linkabit played a major role in advancing and refining digital radio, and deploying military technologies for civilian applications. The firm's major successes included (Morton 1999b; Simard, 2004):

- A military communications modem that used spread spectrum technology and software-based microprocessor encryption to provide secure communications with Air Force nuclear bombers, which was later adopted by the Army and Navy.
- Applying military very-small-aperture satellite (VSAT) communications principles to provide a national communications infrastructure supporting thousands of Wal-Mart and 7-11 retail outlets.
- The VideoCipher encryption system adopted by HBO and other cable TV channels for satellite distribution of original programming.
- The first commercial handset to support U.S. digital cellular standards.

Former Linkabit engineers later founded startup companies to exploit the first two technologies, while the latter two were sold off to other companies.

INTRAPRANEURIAL SKILLS FORM ENTREPRENEURIAL STARTUPS

In hiring a large pool of intelligent, independent and creative engineers, Linkabit faced an intrapraneurial dilemma often confronted by mature high-tech companies. How can a firm develop entrepreneurial innovation capabilities within the firm, while assuring that the benefits of those capabilities accrue to the benefit of the firm rather than leave the firm (and encourage the loss of key workers) through the formation of new startups?

The issue has been a salient one for high tech managers since 1957, when eight employees left Shockley Labs to found Fairchild Semiconductor, and then four years later Fairchild employees started forming their own firms.

An Exploding Seedpod of Entrepreneurship

Brittain and Freeman (1986) concluded that corporate takeover and CEO succession leads to a high probability of employees leaving to form their own spinoffs. These events were crucial in the demise of Linkabit. The innovation capabilities that Linkabit had developed based on its elite yet egalitarian engineering workforce were challenged both by the company's growth, and by a shift in policies and culture under new management.

Like other small innovative companies, Linkabit struggled with the consequences of success. As it won more contracts, the company grew rapidly from 1978-1985. This both diluted the innovation capabilities by reducing the concentration of talent, and also the ability of rank-and-file engineers to reach top managers like Jacobs and Viterbi.

To gain capital to pursue its commercial opportunities, in 1979 Linkabit's executives negotiated an acquisition by M/A-COM, a defense electronics contractor based in a Boston suburb. One of the first aspects of Linkabit's original culture eliminated by M/A-COM was its recruiting policy. Said one executive: "I talked to a Vice President of M/A-COM and his comment to me was 'I never recruit at the top universities because these people don't fit in the company.'" (Interview, June 15, 2004). The existing graduates of elite engineering schools — who once enjoyed the freedom to pursue innovation and creativity at Linkabit — found themselves unable to adjust to M/A-COM's emphasis on managerial expertise. As a former engineer explained, "It went from campus atmosphere of equals to a paternalist culture. Management was up in the clouds" (interview, January 29, 2004).

Eventually, a management shakeup at the parent company prompted Jacobs and Viterbi to leave. They had negotiated the purchase with M/A-COM CEO Lawrence Gould, a former research scientist who like Jacobs held a Ph.D. from MIT. When M/A-COM foundered, Gould was removed as CEO and replaced with a financial manager. As Viterbi explained:

> Viterbi: [I left] because the person who originally acquired Linkabit, the chairman/CEO, was pushed aside by the board around 1983, and after that, things went downhill. I don't mean downhill just economically in business, but [also] in structure and management. (Interview, June 15, 2004).

The departure of the founders, coupled with earlier factors, combined to spur an exodus of Linkabit talent, quickly dispersing Linkabit's innovation capabilities to a variety of other firms. Linkabit employees founded seven new communications companies in the period 1984-1987. The company's satellite, television and defense divisions — comprising the bulk of the original Linkabit — were sold off by M/A-COM in 1986, 1987 and 1990 respectively.

By 1998, alumni of Linkabit (and its spinoffs) had founded 22 new technology-based startups, and Linkabit was credited with incubating a new high-tech economy in the surrounding San Diego region (Markoff, 1997). By 2000, a total of 65 direct and indirect spinoffs had been formed (Figure 1).

Imprinting the Children

Such a high rate of firm formation raises the question of what the entrepreneurs had in common that was passed from the parent to the spinoff companies. The purpose and structure of organizations are imprinted by their founding history, which influences a firm's hiring decisions, ongoing leadership style, and its managerial practices (Stinchcombe 1965, 1986; Kimberly, 1979; Boeker, 1989). In a study of Silicon Valley startups, Baron et al (1999) identified three indicators of managerial practices imprinted on firms by their founding conditions: employee attachment (e.g. a family-like environment; challenging work opportunities), coordination and control (informal/peer versus formal), and employee selection (hiring based on skills, cultural fit, or experience).

While firms may deliberately transfer resources and capabilities to the formal spinoffs that they sponsor, informal (or unsponsored) spinoffs also inherit resources and capabilities from the founders' prior firms (Helfat & Lieberman, 2002; Burton et al, 2002). For example, entrepreneurs often start companies to exploit specific market opportunities they identified while working at their previous employer (Shane, 2000; Klepper, 2001). To ascribe a value for these inherited capabilities, a key issue is the relatedness of parent and spinoff company industries, and thus (for example) the relevance of the technical knowledge related to a specific industry or product segment.

In high technology industries, a common pattern is that employees "leave their employers to start firms in the same industry" (Klepper 2001: 639). Examples include when Gene Amdahl and Seymour Cray left IBM and CDC respectively to found their epynonymous computer companies. In the case of Linkabit spinoffs, a handful of new firms applied technologies pioneered at Linkabit, with a concentration of digital satellite communications among first-generation spinoffs. However, few of Linkabit's 76 direct and indirect successor companies pursued the defense communications niche that enabled Linkabit's growth and exit. Overall, they entered a variety of industries in the telecommunications sector, spanning the 2-digit Standard Industrial Classification (SIC) codes 36, 38, 48, 73, among others. Together, this suggests that shared knowledge of a specific market, product or technology is at best a partial explanation of such entrepreneurial activity.

This raises the question: what was common among the Linkabit children, which made chips, board, systems, services and software? Spinoff founders listed two factors. As with Phillips (2002) study suggesting that parent firms tend to transfer procedures and social structures to their spinoffs, spinoff founders said that they attempted to replicate Linkabit's innovation capabilities: "We built a model of Linkabit – we had too many projects, talented people – we competed with Qualcomm for quality engineers, we went recruit at MIT" (Interview, Nov. 4, 2003). Secondly, the engineer-founders attempting new applications of digital communications emphasized their grounding in the basic principles of information theory. Many were hired because they acquired this knowledge in their college education. However, the Linkabit alumni — as well as veterans of the first round of spinoffs — also learned practical application of those principles on the job. "Viterbi taught me what I call the praying mantis side, the practical side — taking all this theory I had from the classroom and turning it into products that we could build and so on" (Interview, July 17, 2003).

The elite reputation of Linkabit and its alumni had a secondary effect. A key concern of new firms is legitimation and overcoming the liability of newness (Stinchcombe, 1965; Delmar & Shane, 2004). Such legitimacy and prestige can be transferred from parent to spinoff organization (Phillips, 2002). While Linkabit was little known during its lifetime, after its sale and dismemberment it became the local telecommunications industry's most famous company after Qualcomm. The reputation earned by Linkabit and its earliest spinoffs — both from their elite engineers and innovation successes — conferred legitimacy on the first-generation Linkabit spinoffs, successive generations of spinoffs from those firms, and eventually to the entire local industry. The effect was strongest in San Diego, where 66 of Linkabit's 76 direct and indirect descendants were founded.

Limits to the Inheritance

Our study suggests that startups may also inherit disadvantages from their parent. In the Linkabit case, the capabilities that were crucial to exploiting a period of technological discontinuity were transferred to its children but were no longer the most important in a context of maturing technology and increased competition.

Most notably, the success of engineer-founded Linkabit spawned another generation of engineer-founded startups — which, like Linkabit, had little knowledge of mass-market consumer marketing, manufacturing or distribution. As a result, the revenue models of Linkabit descendants largely focused on small numbers of organizational customers — whether government, large companies or component sales to a comparatively small number of systems vendors. Even Qualcomm, a Fortune 500 company and the most successful of the Linkabit spinoffs, had after 20 years only 130 customers for its IPR licensing division, which comprises a superset of the customers of its other major division, cell phone chips.

Neither Qualcomm nor the other descendants were able to master high volume consumer manufacturing or marketing. The two largest attempts resulted in exits within 5 years of initiation. In 1987, Linkabit sold its cable TV operations to General Instruments, an existing maker of settop boxes. Meanwhile, Qualcomm's attempt to manufacture cell phones ended with the 2000 sale of that division to Kyocera.

While it's possible that these missing capabilities were hard to obtain, it is also possible that they were not valued by the engineer-founders. Chesbrough (2002; Chesbrough & Rosenbloom, 2002) concludes that the founders of Xerox PARC spinoffs were eager to escape the limitations of Xerox and succeeded precisely because they were able to escape the cognitive biases of their parent. In the case of Linkabit, the alumni founders embraced and sought to re-create the Linkabit model, and thus most also embraced the Linkabit worldview, complete with its limitations.

<u>Success</u>

What was the success of these spinoffs? Given the large number of private companies, only spotty data is available. The greatest technical and financial success came with Qualcomm, founded in 1985 by Jacobs, Viterbi and five former Linkabit colleagues. The company created the CDMA mobile telephone standard, joined the Fortune 500, and as of this writing holds a market capitalization in excess of $70 billion.

Outside Qualcomm, the most visible technical success came with Linkabit's official spinoff of its VideoCipher division. After its purchase by General Instruments, the team extended the VideoCipher technology to develop the first prototype digital high-definition television system, where teams from Japan, Europe and the U.S. had assumed that only analog technology was feasible (Brinkley, 1997). However, after this episode of innovation, GI and its San Diego division were dragged back into the commodity competition of the settop box industry.

In addition to Qualcomm, four companies went public. The most successful IPO was Copper Mountain, which peaked at a 2000 market capitalization of $5 billion, then crashed with the rest of the telecom stocks until its 2005 acquisition for $10 million in stock. Of the IPO firms, Rhythms NetConnections went bankrupt, while Leap Wireless and ViaSat remain public.

A more common exit strategy for the spinoffs was to be acquired. The most successful of these was Dot Wireless, a Qualcomm spinoff (and competitor) acquired by Texas Instruments after three years for $475 million. For most of the acquisitions, the price was not revealed, and many of these were sold in distress at a deep discount after the 2000 tech stock crash.

DISCUSSION

Implications

We believe this study touches on three important areas for high tech startups: the role intrapraneurial development can play in fueling spinoff formation, the transmission of key resources and capabilities from parent to child, and how the value of innovation capabilities is contingent upon the stage of technological regime.

Intrapraneurial Dilemma. An established company seeking corporate renewal faces a dilemma of how to encourage entrepreneurial activity so that the benefits accrue to the company rather than exporting these resources to entrepreneurial startups. While firms can potentially harness spinoffs for financial or strategic gain, research suggests that these rarely provide the renewal needed to solve the firm's core business problems (Chesbrough 2002).

This dilemma of intrapraneurial renewal applies not only to Linkabit but also the better known example of Fairchild Semiconductor. In the decade 1983-1993, Linkabit formed 17 direct spinoffs, comparable to nearly two dozen Silicon Valley semiconductor firms formed by alumni of Fairchild Semiconductor from 1960-1969 (Lécuyer, 2000). However, counting five generations of startup companies (founded by alumni of Linkabit and subsequent startups), a total of 76 firms were founded in the period of 1983-2003 (Dennis, 2003), compared to approximately 35 direct and indirect spinoffs of Fairchild in the period of 1959-1983 (Lécuyer, 2000; Rogers and Larsen, 1984: 43). This suggests that either the entrepreneurial window of opportunity closed more rapidly for the semiconductor industry, or that the capabilities of the Linkabit veterans were more broadly applicable than those flowing from Fairchild.

The timing of spinoff formation at the two companies implies that it's possible to defer (if not prevent) a high rate of spinoff formation. After Fairchild Camera took control of its subsidiary — changing the culture and management practice — spinoffs were gradually formed, but this accelerated with a management change and departure of two key founders. At Linkabit, the flood of spinoff formation — 7 firms in 1984-1987 — began as all of these factors came to a head in a brief period. This explains Cisco's painstaking efforts to maintain the culture and autonomy of dozens of small companies it has acquired over the last decade (Mayer & Kenney, 2004).

Sources of Capabilities. The 76 direct and indirect spinoffs received key resources and capabilities from Linkabit and it successors. The first generation spinoffs were seeded with crucial resources — the talented Linkabit alumni. At the same time — as with the Silicon Valley startups studied by Burton et al (2002) — these alumni brought a legitimation to the startups from their former employer's prominence.

These workers — particularly the founders and earliest employees — provided the startups' key initial capabilities, carrying with them both explicit and tacit knowledge of how to exploit the technological opportunity. Of equal importance to their innovation capabilities, the startups also inherited the competence to apply those knowledge resources, through a culture that enabled creativity and entrepreneurial activity, as well as valuing and seeking out high-potential engineers in the recruiting process. As with other technology clusters, both the supply of key resources and the associated innovation capabilities fueled a positive feedback loop that made it easier for new firms to form and grow in the local environment.

However, it's not enough to have strong initial capabilities: firms must also maintain and augment their capabilities. As a firm ages, the initial capabilities can atrophy or decay, while new capabilities are required succeeded under new conditions.

Contingent Value of Innovation Capabilities. We know that the value of specific capabilities depend on the environmental context (Collis, 1994). How does the value of these innovation capabilities vary with the maturity of a technological regime? A new regime begins with a technological discontinuity that initiates a period of high technological and market uncertainty, providing an opportunity for firms that are able to resolve these uncertainties.

While startup firms are often held to enjoy the greatest potential to exploit a new technology, this is not always the case. In studying the postwar launch of television manufacturing, Klepper & Simons (2000) conclude that the most likely to survive were high-volume radio manufacturers, as experienced radio engineers applied their innovation skills to the new technology. But they note the U.S. television industry was one of unusually low uncertainty, with well-established compatibility standards, proven technological and economic feasibility, and a prolonged incubation due to World War II.

In contrast, we believe the high rate of new entrants in digital telecommunications reflected high levels of uncertainty from 1975-2000. In the earliest period, the uncertainty related to the actual potential of the key component necessary for implementing new systems, i.e. the microprocessor. In the middle period, engineers sought to understand how digital communications could be used to improve the performance of existing analog systems (e.g. in television, mobile phones). The remaining uncertainty — over the nature and degree of market adoption — was resolved during the final period, during both the great boom in Internet and (in the U.S.) mobile phone adoption, and also the subsequent crash.

At the same time, the modest economic success of the Linkabit spinoffs suggests that they were generally unprepared for the previously-identified pressures that come with the growth and eventual maturity of a technological regime. As a regime matures, opportunities for product innovation become more incremental, while cost reduction, quality improvement and other manufacturing-related capabilities become more important. With increased volumes, firms also need capabilities for marketing, distribution, manufacturing and reaping economies of scale (Teece, 1986; Klepper & Simons, 2000; Moore, 2005).

Future Research

While we enjoyed rich data for a large number of companies, inferences from this data must be tempered by key omissions. Due to the wide spread of the Linkabit spinoffs across various industries, we currently lack control data as to the number and performance of other (non-Linkabit) startups entering similar industry segments. We also have only incomplete data for one performance measure (survival), and given the lack of public companies, are unlikely to obtain other measures. Future research would establish whether these results are robust to more rigorous performance measures.

We believe these findings suggest two future research topics related to the opportunities for entrepreneurial startups during a period of technological ferment.

The first lies over subsequent patterns of intrapraneurial spawning of spinoffs. While Linkabit (and Fairchild) spawn large number of companies, anecdotal data suggests that their successors (Intel, Qualcomm) do not. If so, is it because the spinoff founders consciously adopted policies to retain key workers, or because their financial success made it harder to leave? Or is it because the opportunities for forming new firms (or forming major new firms) are lower? Or is the rate unchanged, but the spinoff formation merely less visible?

The other relates to the difficulty technology startups (particularly engineer-founded ones) have in augmenting their missing capabilities. This study shows one source for innovation capabilities suitable for early stages of a technological regime. But how do the most successful young firms develop the complementary capabilities necessary for survival? Does the external discipline of outside investors force founders (particularly engineers) make them more likely to develop such capabilities? Do these capabilities better explain success than other measures (access to capital, choice of technology or market niche), or is there a causal relationship between them?

CONTACT: Joel West, Lucas Graduate School of Business, San José State University, San José, CA 95192-0070, Joel.West@sjsu.edu, www.joelwest.org

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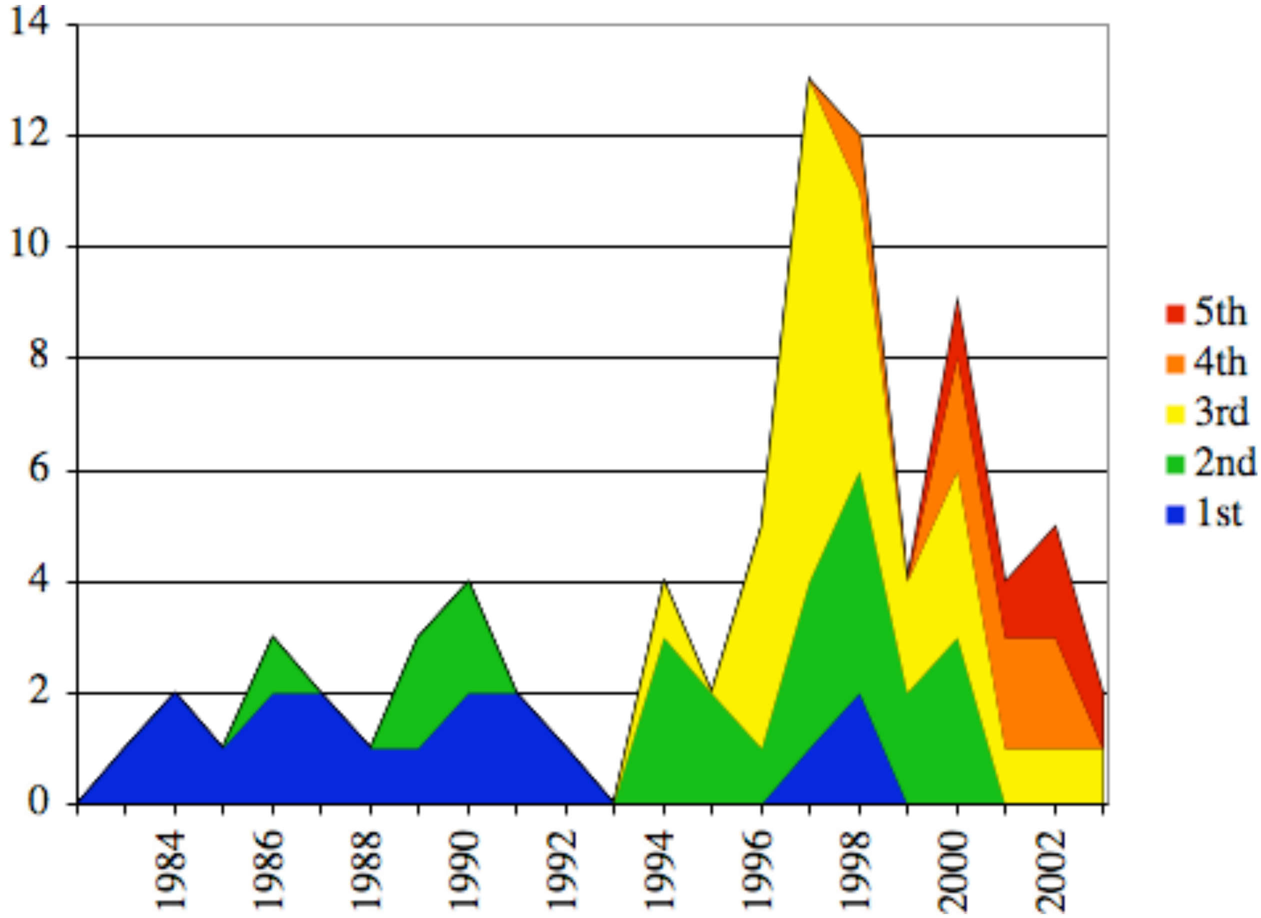
Date	Event
1966	Irwin Jacobs leaves MIT faculty to join UCSD
1968	Linkabit founded in Los Angeles by three electrical engineering professors: Irwin Jacobs (UCSD), Andrew Viterbi and Leonard Kleinrock (both at UCLA)
1968	Kleinrock leaves Linkabit; later works on packet switching and the ARPAnet
1969	Linkabit hires its first full-time employee, Jerry Heller
1970	Linkabit moves to San Diego
1971	Jacobs takes leave of absence from UCSD to run Linkabit full-time, never returns
1973	Viterbi moves to San Diego to work full-time at Linkabit
1978	Viterbi elected to National Academy of Engineering
November 1979	M/A-COM announces it is acquiring Linkabit
August 1980	Linkabit acquisition completed at a price of $25 million
1982	Company changes name to M/A-COM Linkabit
July 1982	M/A-COM board removes Lawrence Gould as CEO
January 1983	HBO signs contract to buy Linkabit Videocipher scrambling hardware
March 1983	Gould's term expires as chairman and director of M/A-COM
April 1985	Jacobs and Viterbi quit Linkabit
June 1985	Jacobs, Viterbi and 5 Linkabit alumni found Qualcomm
January 1986	HBO and Showtime begin scrambling satellite distribution of programming using Linkabit technology
September 1986	M/A-COM sells Linkabit VSAT business to Hughes for $105 million
September 1987	Linkabit commercial TV unit sold to General Instruments for $220 million
June 1990	Linkabit government contracting business sold to Titan Systems for an unspecified amount
December 1991	Qualcomm IPO raises more than $70 million
December 1994	Jacobs awarded National Medal of Technology by President Clinton
June 1995	AMP acquires remainder of M/A-COM for $390 million
April 1999	Facing a hostile takeover threat, AMP sells itself to Tyco International

Table 1: Milestones for Linkabit and its founders



Source: Dennis (2003)

Figure 1: Startup formation rate for five generations of Linkabit spinoffs