Institute for Manufacturing

Centre for Technology Management

Growth Processes in New Technology-based Firms and their Co-evolution in Emerging sectors

Elizabeth Garnsey

Final report for ESRC Award L326 25 3049

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ESRC Priority Network on Complex Dynamic Processes

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Executive Summary

This research aimed to provide an integrated and dynamic perspective on the emergence and evolution of new knowledge-intensive firms, informed by complexity thinking.

(1) While growth performance of European high tech firms has been a cause for concern, the nature of their unfolding growth experience had not been examined in the cross sectional surveys of new firms' growth rates and success attributes that dominate the literature. We explored metrics on firms' growth that could track trajectories and turning points over time. Data on 2000 Cambridge high tech firms was refined from County and commercial databases to trace growth performance between c.1990 and 2000. Continuous growth was rare (around 5% of a cohort). Even in firms with an early growth record there was a propensity for growth to be interrupted and reversed, though recovery also occurred (Garnsey and Heffernan 2002; 4). The methodology we developed was applied to German, Dutch and French datasets by collaborators whose findings confirmed patterns of uneven growth among other new European high tech firms (Garnsey, Heffernan, Hugo 2002, Garnsey et al 2003).

To explore growth mechanisms and processes in more detail we carried out 24 UK case studies and used US cases as comparators. We found that team responses to constraints were a source of breakthrough**:** technologies developed under pressure to solve critical problems became a key resource providing competitive advantage. Constraints making it necessary to enlist allies in the venture provided new access to resources. This evidence informed a conceptual model explaining the diversity-creating effects of entrepreneurial problem-solving (Garnsey 2004). We refined our resource-based model of technology ventures to explain the high incidence of uneven growth, the evolving nature of business models and how it is that entrepreneurial responses to setbacks can open unexpected opportunities (Hugo and Garnsey 2004).

(1) Processes of co-evolution as firms grow in a dynamic environment were explored (a) in studies of emerging international industries and (b) in studies of high tech clusters in the Cambridge area.

(1a) A review of the ***emergence of IT sectors in the US*** revealed how dynamic processes in networked industries result in markets tipping towards the competing technology that rapidly achieves a critical mass of customers (Garnsey et al 2004). Young companies with closed proprietary technologies were eliminated or eventually relegated to niche status, e.g. Laser-Scan, Acorn and Psion. In the ***PC, PDA and GIS sectors*** growth interruptions prevented other UK ventures becoming international leaders. Growth has been better sustained in non-tipping markets such as industrial Ink Jet Printing and security software. Experienced entrepreneurial teams (e.g. ARM, CSR) now aim to create alliances to support their technology standard (Garnsey and Heffernan 2005).

Leading US start ups with new IT technologies experienced growth problems but these were mitigated by market-ready technologies and greater availability of capital. They expanded their installed customer base much more rapidly than pioneering UK firms which had comparatively low levels of investment. In the Cold War, US government investment provided IT technologies ripe for VC investment and rapid scale-up. Entrepreneurs excel at exploiting market-ready technologies that are in the public domain; long and costly technology development can drain entrepreneurial time and ingenuity (Maine and Garnsey 2004).

The study of ***UK bio-pharmaceuticals*** revealed inventive attempts to address problems of funding long term development of science-based ventures through VC and new types of business model (Garnsey 2003 Lim, Garnsey, Gregory 2004)). The ***ink jet printing (IJP) sector study*** revealed the cumulative building of capability through spin-out in the creation of Cambridge clusters and supplier networks, where a leading firm (Domino Printing Sciences) helped create an enabling environment for related firms. Expertise in IJP in

the area is supporting the emergence of a high potential new sector, plastic electronics (Garnsey and Heffernan 2005).

(2b) Because knowledge developed in the science base constitutes a critical resource, we conducted case studies of academic entrepreneurs, start ups and spin outs (Druilhe and Garnsey 2002, 2004). The spin-out process has been multi-generational and has given rise to local clusters of activity and social capital formation (Garnsey and Heffernan 2004). A French comparison, with Sophia Antipolis, revealed the higher incidence of indigenous enterprise in the Cambridge area and fewer implanted corporations (Garnsey and Longhi 1994a/b). But the presence of telecommunications standards institutes in Sophia-Antipolis (e.g. ETSI and W3C) encourages local awareness of the benefit of participation in standards - setting.

(3) Theoretical Perspectives

New firms using their own revenues to develop their resource base are vulnerable to cash flow crises, especially where capacity increases in uneven steps and the demand curve is unpredictable (figure 1).

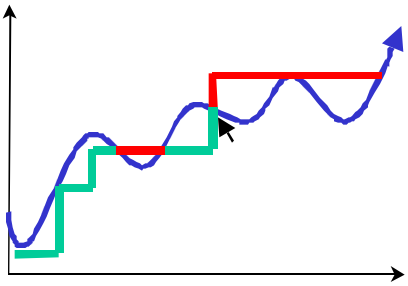


Figure 1 Firm scale up under uncertain demand and uneven capacity expansion

However, the difficulties encountered stimulate entrepreneurial experiments. Our model of the entrepreneurial process complements the “search and learn’ models of complexity developed by Peter Allen (Garnsey 2004). Proactive individuals can set off cascades of follow-on activity, resulting in expanding networks and clusters. Spin-out activity is revealed as a reproductive process that creates local knowledge clusters. In a self-transforming process new firms co-evolve with other organizations, collectively shaping industries and local clusters of activity

Policy implications

Public investment in knowledge-based sectors creates positive externalities. Even when individual firms fail and falter, dynamic processes extend beyond recognized ‘spillovers’ to encompass knowledge-recycling, resource reconfiguration and multi-generational spin-out, yielding wider economic returns.

Growth problems are endemic in resource-limited new firms. Investor expectations of continuous growth are therefore unrealistic. Our research suggests that it is inventive responses to constraints that are critical. Entrepreneurs alert to shifting possibilities for new resource creation have turned constraints to advantage, for example by developing partnerships or reinventing the business model to seize new opportunities.

However resource constraints limit the range of opportunities that can be addressed. The range of business experiments in emerging sectors reflect the opportunities open to UK ventures. We found a narrow range of business models: consulting, licensing and outsourcing predominated. Early sales to foreign acquirers were common among promising young companies. Where this results in further spin out and VC activity there are local multiplier effects. But the UK investment market is focused on short term returns, penalizing ventures that incur the irrecoverable costs inherent in building long term capability, particularly in emerging technologies that provide the basis for future growth. Policy should aim at creating an environment more conducive to independent growth and sustained returns among new knowledge-based companies. Other industries benefit from the flow-through effects of technologies developed by technology-based enterprise, as revealed by the retail sector’s reliance on IT innovations emanating from such companies.

FULL FINAL REPORT Elizabeth Garnsey rev. Dec 2004

ESRC AWARD REF L326 25 3049

GROWTH AND CO-EVOLUTION AS COMPLEX DYNAMIC PROCESSES IN HIGH TECH ENTERPRISE

Introduction and Objectives

The project adopts an integrated approach to the emergence and evolution of new knowledge-intensive firms and industries, viewed at various levels of analysis with a focus on entrepreneurial business development. The research is influenced by complexity ideas and informed by specific findings from quantitative and qualitative analysis.[1] The objectives of the project have been achieved and its scope extended through collaboration.

Complexity ideas provided conceptual grounding for examining the non-linear process of knowledge commercialization and the clustering of innovative activity. We found growth problems to be endemic in resource-constrained new firms because their innovative advantage is gained from operating at the edge of what is possible. A revealing set of new firms is made up of those that perform well early on but run into difficulties. The causes are not captured by standard cross sectional surveys which emphasise reported constraints, success attributes and mean growth rates. Averaging out growth rates conceals significant patterns in firms' growth over time. 'Success attribute' studies overlook the importance of cognitive factors – perceptions of and responses to constraints and opportunities. Formulae for averting growth crises are unlikely to be realistic in an ever-shifting environment. Instead, the research points to the benefits of positive responses by entrepreneurial founders and managers to the difficulties they encounter. Responsiveness calls for continual opportunity scanning and resource-building, readiness to shift strategic direction and a support network providing access to resource inputs at critical junctures. There is great benefit in understanding the evolutionary dynamics of technological, market and industry cycles.

[1] One half-time research associate (Paul Heffernan) was funded by the ESRC for three years and one principal investigator (Elizabeth Garnsey) undertook to contribute twelve hours per week. Funding for associated doctoral research projects was obtained from the AGF (for Hugo), from EPSERC (for Dee

Methodology

Complexity ideas influenced our methodology. We originally envisaged two levels of analysis, the new growing firm and the sector in which it operates. But in recognition of the tiering of complex dynamic systems (figure 1) our investigations came to be organized at a number of levels: the entrepreneur, the new venture and the industry sector and local cluster that constitute their environment. At each level we conducted quantitative and /or case analysis.

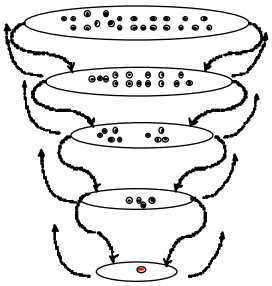


Figure 1 The Tiering of Complex Adaptive Systems

The creation of novelty and its subsequent selection or elimination by evolutionary mechanisms is a central theme in complexity studies. We examined the evolution of a number of emerging sectors to explain linkages between the dynamic processes of variety generation, selection and propagation (Garnsey, Heffernan and Ford, 2004). We conducted a review of personal computers and electronic messaging sectors and investigated conditions for new firm growth in biopharmaceuticals and ink jet printing sectors through interviews.

Models and Findings; the evolution of ICT technologies

We found that inventions and technological advances, mainly funded by public expenditure, created openings for new entrants who assumed the role of agents of change. In networked industries, new technologies are subject to network externalities, with the processes of selection and propagation fundamentally linked. In a highly networked industry like the PC industry, markets tip towards the dominant technology (towards MS-DOS and the PC) as illustrated in figure 2

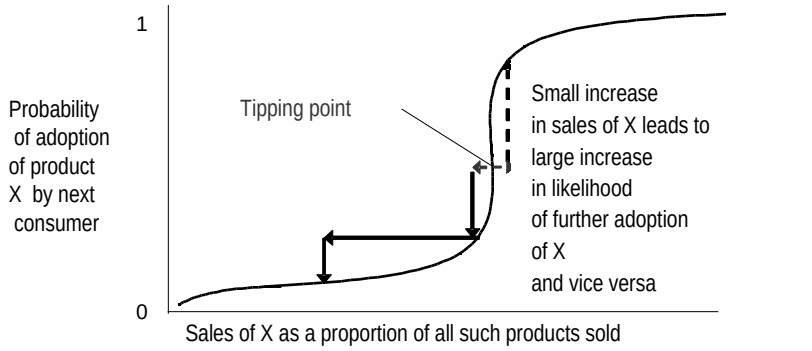
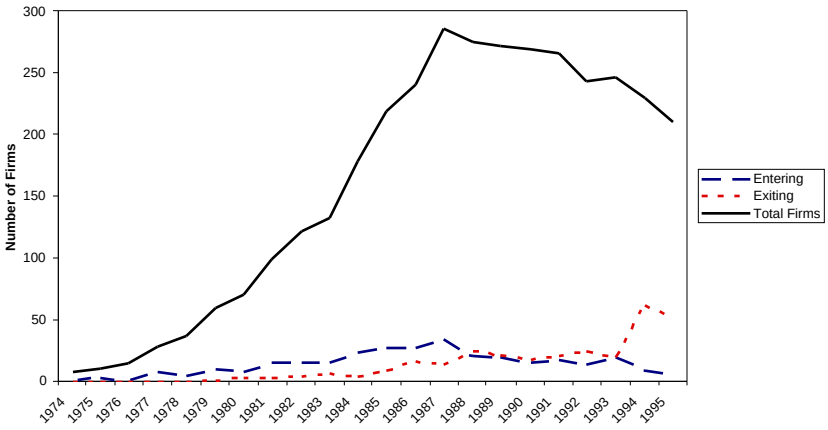


Figure 2 Networked markets tip towards dominant technologies

Positive feedback mechanisms in producer and consumer ecosystems reinforced future selection, with a dominant design emerging once a critical mass of users has been achieved. These mechanisms include: the need for interoperability; user learning effects and the development of complementary technologies. Subsequent innovation around dominant designs is incremental and further variety generation derives from the development of complementary technologies. This investigation provided theoretical underpinning for our finding that technology based firms represented by our UK case studies (Acorn, LaserScan and Psion) ran into difficulties when a rival technology standard created a larger installed base and displaced their proprietary technology. Thus Acorn's growth was limited by the dominance of the IBM PC. An analysis of firm numbers in the PC sector showed that the industry shake-out coincided with the emergence of the IBM PC and Microsoft's operating system as the dominant design in around 1987.



Source: International Data Corporation PC database

Figure 3 Entry, exit and total numbers of firms, PC sector 1970-2000

The GIS sector, another networked industry (Heffernan and Lim 2003) confirmed trends towards concentration and elimination of firms with closed proprietary technologies. One of our case study firms, LaserScan, was adversely affected by delays in moving from VAX to UNIX and by the growth of Windows based GIS software. Local experience has made Cambridge technologists are increasingly aware of the importance of forging industry standards in emerging technologies.

Our second investigation at the industry level aimed at exploring the adoption of IT technologies by a major UK sector. The objectives of this study were to explore the importance of innovative new ICT firms by looking at the flow-through into established sectors of the economy of enabling technologies emanating from new firms. UK retailing is among the most IT intensive sectors in the economy. Among the most significant IT technologies introduced in retailing were those initiated by US Internet pioneers: work stations, network software, routers, servers and search engines. All these technologies originated in university spin-outs including Sun, Netscape and (two of our comparator US case studies), Cisco and Google. We carried out a complexity-inspired study of the role of IT technologies on innovation in supplier organization in food retailing, synthesising secondary materials and conducting interviews with industry experts on use of technology. We found

that Internet software had made it possible for the supermarkets to handle the massive amounts of information they required in order to lower supply costs. In the face of information overload, self-organizing processes pioneered in packet switching technologies were allowed to filter and provide relevant information. Finally, the supermarket sector illustrates the elimination of diversity of retail outlets in a mature, highly concentrated industry, highlighting the contrast with the diversity-creating influence of emerging firms in emerging industries (Frances and Garnsey 2001).

The third industry-level investigation undertaken was of bio-pharmaceuticals. Our original aim was to apply the resource-based model of firm growth to a sector in which new venture growth appeared aberrant since employment growth precedes revenues from the product (Garnsey 1998). Investigation showed that bio-pharmaceutical ventures are not aberrant, but are responding, as do other new ventures, to selection forces. The diversity of business models being pursued by biopharm ventures reflects problem-solving within constraints of the kind predicted by our model of entrepreneurial diversity-generation (Garnsey 2003). There are tensions between the short term pressures of the capital markets and necessarily long term development cycles in a highly regulated industry. Because they are embedded in the institutions of science, health and investment and have dedicated sources of finance, these ventures face a unique selection environment. Their relations with large pharmaceutical firms and the influence of regulations and intellectual property arrangements are distinctive (Lim, Garnsey and Gregory 2004). But the very distinctiveness of biotech ventures illuminates the way selection forces shape developmental processes in all new firms. Applying our models to the biopharm sector showed the way evolutionary theory and complexity approaches complement and complete resource based theory.

Studies of the GIS sector and the industrial ink jet printing industry (Garnsey and Heffernan 2005 forthcoming) provided background to the investigation of local clustering of high tech activities examined below.

Entrepreneurial level

Despite increasing interest in the topic of entrepreneurship, the actual processes by which the entrepreneurs operate as agents of diversity creation had not been explained. Peter Allen has modelled the "search and learn" techniques of ventures with innovative products, which operate as complex dynamic systems (Allen 2004). We aimed to provide qualitative modelling of the entrepreneurial process to inform this type of formal model.

Our case studies showed that entrepreneurial opportunities do not lie waiting to be discovered but are brought into being (enacted) - by entrepreneurs. They continually reassess their initial conjectures as they attempt to resource their venture. Chronically short of resources, they experiment with means through ***resource economy, resource leverage, new combinations and resource creation***. They achieve this by networking to find others who will trade resources now for a share in future returns. It is by enlisting others that entrepreneurial ventures create opportunities, mobilizing resources to create value and secure returns. The problem-solving within constraints in which entrepreneurs engage gives rise to unexpected solutions, as in other forms of creative endeavour that include scientific discovery (Garnsey 2004). Collectively, individual efforts to secure returns in new ways operate to generate diversity.

In the economy, entrepreneurial openings stem from endemic asynchronies in supply and demand. These have been identified with the 'market failures' of orthodox economics. In contrast, we see conditions of 'market failure' (e.g. asymmetrical information) as the predictable outcome of market dynamics and the very conditions that make innovation possible (Garnsey 2004). We concur with Metcalfe as to the inappropriateness of conventional market failure terminology. Entrepreneurial innovation is essentially a dispersed process. Any one new venture is likely to succumb to unsolved problems or to grow conservative, but there are a number of key successes among the many diverse trials. Wave after wave of new entrants create and propagate new varieties of output and activity, renewing industries over time (Garnsey 1998).

This conceptual framework reapplied to case studies revealed the limitations of attribute based studies of new firm growth performance (Hugo and Garnsey 2002; Hugo and Garnsey 2004). The poor predictive record of studies analysing success attributes and favourable initial factors as determinants of new firm growth results from the diversity of entrepreneurial responses to problems of growth. We examined entrepreneurs who were able to overcome adverse the initial conditions of their ventures despite the lack of early 'success attributes,' by finding alternative opportunities and by achieving resource economy, resource leverage and resource creation. Strategic relationships formed with other players were critical. Spurred by the problems they encountered, entrepreneurial firms had recourse to new solutions, their business model evolving as a result of changing conditions and increased experience. Firms active in a niche market that expanded into a major new sector were well placed to grow with the market - so long as they could scale up effectively. Effective procedures for dealing with scale-up were introduced by experienced managers in the more successful cases (e.g. ARM, Micromuse and Virata). Where predictable growth requirements (assimilation of new recruits, streamlining of production processes) went unmet, costly delays ensued.

University spin-out ventures

We undertook a number of case studies of new firm emerging from the university to gain a better understanding of knowledge as a source of competitive advantage, on the one hand, and difficulties of commercialization on the other (Druilhe and Garnsey 2003; 2004). There has been a widespread tendency to view academic spin-outs as an undifferentiated category. We used a Penrosean conceptualization of entrepreneurial activity to develop a typology of spin-out activity, taking into account the non-linearity of the entrepreneurial process.

Results of the inquiry showed that as university ventures evolved, their entrepreneurs tried out alternative models of business activity, ranging from consultancy to in-house production. The diverse activities of spin-outs require more varied metrics on commercialization than are currently in use. Over

time, university based entrepreneurs were responding to the UK environment and local business culture by a move away from business models that require long term investment in favour of consulting and licensing models that require less immediate commitment of resources. This was confirmed by the study of spin-out activity from engineering, computer science and the life science departments (Garnsey and Heffernan 2005).

Local clustering: the Cambridge Case

Along with an overview of the role of the science base in the emergence of Cambridge high tech industry, we sought to examine the co-evolution of firms in the local environment. Our aim was to explore how the growth of individual firms may be influenced by their location and the presence of other knowledge-based organizations in the area. We examined local capability, using as measures evidence on firm foundation and survival rates, technology transfer, the availability of investment capital and export activity (Garnsey and Heffernan 2005). Data on sectoral distribution of activity and on clusters of firms with common origins signal changing areas of local competence and the role of key individuals in local networks. Cambridge high tech industry is characterised by knowledge clusters that take part in international production chains and provide specialist labour markets. We found that spin-out activity has been the engine of local innovative activity, creating knowledge-based clusters that have attracted other related organizations to the area. We examine the emergence of new forms of collective enterprise addressing local problems and the role of social networks in this process.

Further evidence of the importance of unusual people emerged from this inquiry. The growth of high-tech industrial activity in the Cambridge area has generated a pool of people who have been involved in the foundation and development of new firms. These experienced entrepreneurs and managers contribute to the industrial community in a number of ways:

- ***As serial entrepreneurs*** responsible for a series of start-ups, often in different sectors.

- ***As mentors to new entrepreneurs***. A network of support structures has emerged, with organisations such as Cambridge Enterprise bringing together mentors and new entrepreneurs
- ***As business angels and venture capitalists***. Venture Capital firms such as Amadeus Partners adopt a hands-on approach, helping to build new teams and recruit leading figures onto their Boards
- ***As members of new start-up teams***, bringing with them prior experience.

The knowledge and learning generated through entrepreneurial activity is in these ways being shared and regenerated in such a way as to build and renew social capital (Garnsey and Heffernan 2005).

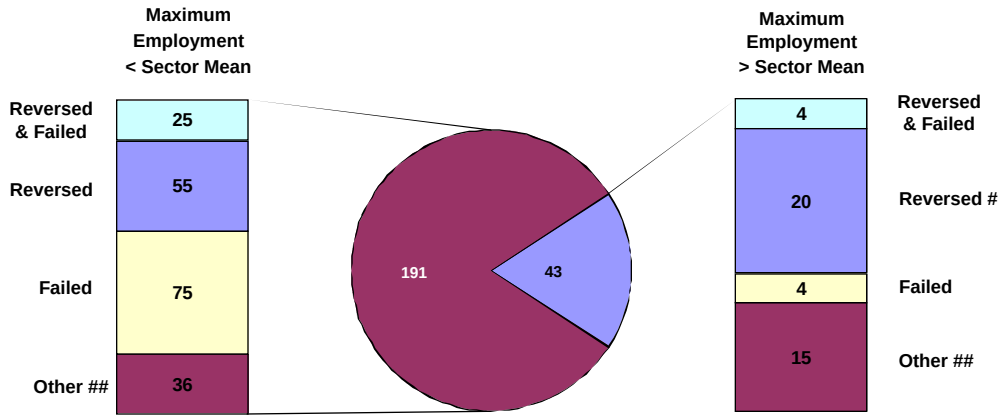
Metrics on 1500 Cambridge high tech firms, 1988-2000

An area of research central to our inquiry concerned growth patterns of high tech firms. These were investigated in a quantitative study of 1500 Cambridge high tech firms. The principal investigator had been collaborating with the County research group on an archive of high tech firms since 1988. Refining this confidential data and purchase of complementary commercial data made it possible to track the performance of newly founded firms over ten years from 1990. The challenge of this part of the analysis was to find suitable forms of compression which could convey not only the rate of growth but fluctuations and variations in magnitude, direction, duration of growth, decline and stability. No standard statistical measures were available. Analysis and coding techniques were developed to convey the uneven nature of firms' growth paths, and applied to other datasets by collaborators, yielding consistent findings (Hugo and Garnsey 2002; Garnsey, Stam et al 2003). The growth pattern analysis by cohort revealed the impact on firms' performance of being founded during a recession.

A resource based model of new firm growth was refined and used to assess a number of propositions derived from our conceptual models. These were investigated in a cohort study of 237 firms founded in Cambridge around 1990. For example: (1) ***New firm growth is uneven***: only 6% of Cambridge high tech

firms founded in around 1990 achieved steady growth over a ten year period, with another 14% growing continuously after an initial delay. (2) ***There are turning points in new firms' growth paths,*** which are marked by growth interruptions and setbacks. (3) ***Firms that do not grow are more likely to close***. (4) ***Firms can recover from performance setbacks*** and resume growth through new resource injections and changes in strategic. We examined firms achieving a higher level of employee growth than the average ***for their sector*** to explore the diversity of growth patterns exhibited (figure 4).

Figure 4 Growth Experiences of a Cohort of Technology-based Firms Commencing Operations in Cambridgeshire between 1989 and 1990



In 17 cases reversal occurred with employment already greater than or equal to the sector mean. In 3 cases the firms grew to greater than or equal to the sector mean after the reversal. One firm suffered reversals both before and after achieving the sector mean.

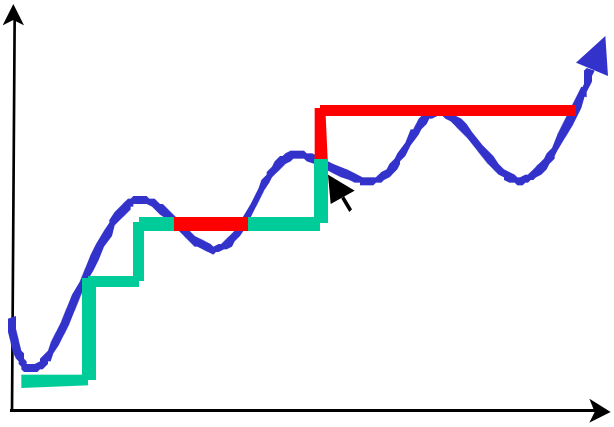
Other includes firms which moved away from the Cambridge area.

Growth asynchronies in the expanding firm

Among the factors underlying fluctuating growth rates are asynchronies between capacity and demand. Because resources can only be obtained in uneven multiples, capacity expands in uneven steps (figure 5). If demand, shown by the curve in figure 5, is unstable and unpredictable, if the venture expands capacity but miscalculates demand, the costs of production will not be covered by revenues. Unless the firm holds or has access to reserves, a cash flow crisis is likely. But the new firm that fails to expand capacity may be caught on a plateau, their position threatened by rivals building market share. The benefits to a venture of operating as a spin-out result not only from better

understanding of the industry and a more mature technology, but from the availability of reserves from earlier returns. These can help weather the fluctuations in performance that result from growth non-linearities. Many of the successful firms we studied were spin-outs that benefited from learning and resource accumulation that had taken place in the parent company.

Figure 5 Non-linear expansion of capacity and demand



Merger and acquisition activity has important implications for the growth of young firms, both in terms of access to resources and remote decision-making. It was found that around half the firms in the Cambridge database were independent in 2000, many firms having been acquired, while others were established from the outset as subsidiaries. Growing firms were most often the targets of acquisition, and these firms continued to grow after the change in ownership. Firms which were not growing prior to acquisition frequently experienced growth as subsidiaries. Initial findings indicate that acquisition generally has a beneficial effect on the growth of young technology-based firms. However case study evidence showed that the effects on the acquired unit's innovative capacity and propensity to remain located in the area following acquisition are in question.

This research provided leverage, enabling us to influence the specifications of research on the local economy commissioned by the Greater Cambridge Partnership from PACEC. We were invited to discussions with members of

the new investor-consultancy, Library House, who were starting data collection efforts for investors.

Implications for business support and enterprise policy

Business development

Technology entrepreneurs need more detailed information on markets and technologies but also a broader education in business dynamics than is currently provided in entrepreneurship training with its focus on start up and the business plan. The co-evolution of firms and their ecosystems opens opportunities for entrepreneurs to influence their environment. But the operating environment can change rapidly under the influence of actors both within and outside traditional market or industry boundaries. Technology standard setting (de facto and institutional) influences industry evolution.

The prevailing emphasis on rapid continuous growth raises unrealistic expectations in investors and does not prepare new entrepreneurs for what lies ahead, leaving them vulnerable to sudden shifts in resources and opportunities. The research indicates that investors, entrepreneurs and managers should shape business plans and strategies to take account of the obstacles and challenges most likely to arise, and focus their attention on building the competencies and alliances necessary to deal with these challenges.

Government policy:

- The uncertainties and costs of understanding emerging markets could be reduced by the provision of government sponsored marketing information relevant to start-up firms with emerging technologies or operating in emerging technology sectors.
- Some of the uncertainties in technological developments could be addressed by providing or subsidising regulatory testing and certification (e.g. at university or government laboratories).
- The overheads involved in taking part in developing industry regulations are high. This tends to exclude new firms from playing a part in technology

standards-setting processes. Subsidies to small firms to take part in industry-wide working parties might increase their level of participation.

- Alliance creation could be facilitated by networking events and associations in emerging sectors.
- Government policy is required to offset the short term focus of current capital markets as this affects new firms commercializing emerging technologies. SBIR provides an example of successful Federal policy in the US.

Policy makers should take into account the positive externalities of investment in emerging technologies and enterprise. Entrepreneurial innovation is a dispersed process; many do not succeed, but there has been a cumulative expansion of expertise and capability, creating a dynamic business community in the Cambridge area. No other such centre demonstrates so well the benefits to the economy of investment in science and technology.

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