Small Firms, Innovation and Industrial Change

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1. Introduction

The role that small firms play in technological change and economic growth has been a subject of debate amongst economists for many years. While some notable economists such as J. K. Galbraith (1957) have argued for the importance of large size and monopoly power others, such as E. F. Schumaker (1973), have argued strongly that "small is beautiful". J. J. Schumpeter (1910; 1943) suggested initially that it was the exceptional creative drive of independent entrepreneurs, undertaking risky innovative developments, that led to the launch of radical new products and new industry sectors which changed existing market structures, and later that it was 'endogenous' science and technology, mainly within the R&D laboratories of large firms, that played the dominant role, increasingly substituting for the mechanism of the 'exogenous' inventor setting up in business. This suggests that the relative roles of small and large firms in technological change and industrial production might vary considerably over the industry cycle.

Many arguments have been put forward for the public support of small firms (Rothwell and Zegveld, 1982). Amongst the general (social) policy arguments are:

- small firms are an important countervelling force to the 'evils of monopoly';
- small firms are a buffer to sharp fluctuations in employment;
- the quality of working life in small firms can have certain advantages over that in large firms;
- the diversified products of small firms are able to cater to the individual tastes of consumers.

Historically, the attitudes of government to small firms have varied considerably, both between countries and over time within countries. In the United States, for example, the argument in favour of protection of, and assistance for, small business has been very strong and is summed up succinctly in the following extract from the US Small Business Act of 1953:

> The essence of the American economic system of private enterprise is free competition. Only through full and free competition can free markets, free entry into business, and opportunities for the expression and growth of personal initiative and individual judgement be assured .... Such security and well-being cannot be realised unless the actual and potential capacity of small business is encouraged and developed. It is the declared policy of Congress that the Government should aid, counsel, assist and protect as far as possible the interests of small business concerns in order to preserve free and competitive enterprise ...

During the 1950s and 1960s, in most European countries government attitudes towards small firms contrasted sharply to those articulated in the United States. Public policies favoured large firms and national 'flagship' companies were created in key sectors such as computers, capable of competing in world markets. The bulk of public sector R&D funds went to large firms, often in support of prestigious "lobby" projects of dubious commercial potential, or to marginal projects that large firms were not prepared to support from internal funds. The small firm sector's share in public funds was minimal during this period.

From the early to mid-1970s onward, European

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government attitudes shifted sharply in favour of small firms, and many public policy measures were introduced in their support. This shift in firm size emphasis was based on the belief that small firms were more efficient employment creators than their larger counterparts; that small firms were potentially a more suitable (endogenous) vehicle for the economic renewal of the less favoured regions than were the branch plants of larger firms (the traditional vehicle of regional policy); and that small firms had a higher inherent innovatory potential than large firms.

Most of the evidence supporting the employment creating role of small firms derived from the United States. A widely publicised report by Birch (1979), for example, based on an examination of employment change in 5.6 million US business establishments, which suggested a high rate of employment creation in small businesses, was taken up enthusiastically by many European policymakers. Earlier reports suggesting the employment creating potential specifically of technologicallly innovative small firms were also influential in Europe (American Electronics Association, 1976; Morse, 1976).

Similarly, US examples of economic prosperity created by "local" industrial agglomerations, including in them many high technology small firms (specifically Silicon Valley and Route 128), highlighted the important role technology-based small firms could play in regional economic renewal, This contributed towards the recent strong European trend towards the establishment of science parks and technopoles as foci for local technology-based industrial development (Sunman, 1986; Rothwell *et al.*, 1988).

During the 1980s European public policies, while still supporting small firms in general, have focused increasingly on measures designed to stimulate the creation and growth of new technology-based firms (NTBFs). This focus has been based to a significant extent on a recognition that NTFBs played an important role in the United States in the emergence of new, high technology product groups such as semiconductors, computer-aided design and micro-computers (Dosi, 1984; Kaplinsky, 1982).

2. Small firms and innovation

Figure 1 lists the advantages and disadvantages generally ascribed to small and large firms in innovation. It is clear from the various statements that innovatory advantage is unequivocally associated with neither large nor small firms. The innovatory advantages of large firms are in the main associated with their relatively greater financial and technological resources, i.e. they are *material* advantages; small firm advantages are those of entrepreneurial dynamism, internal flexibility and responsiveness to changing circumstances, i.e. they are *behavioural* advantages. Large firms that combine both material and behavioural advantages are, of course, in an extremely strong position and it is to this end that major US companies such as 3M have attempted (in most cases with only limited success) to establish internally small firm-type structures to enhance their innovativeness (Hlavacek, 1974; Roberts, 1977).

While a number of studies have highlighted the contribution of small firms to innovation in the United States (NSF, 1976; Morse, 1976; NSF, 1979), European data on this issue generally are sparce. A notable exception is the Science Policy Research Unit's innovation database which contains details on some 4400 significant innovations introduced into commercial use by British companies between 1945 and 1983 (Robson and Townsend, 1984). Figure 2, based on the SPRU data plots, for eight different time periods between 1945 and 1985, the share of innovations gained by firms in five size categories. Perhaps the most notable feature of the data is the increasing share of national innovations taken by small firms (employment 1—199). For small and medium-sized firms (SMFs — employment between 1—499), the innovation share increased from 22.6 per cent during 1965—69, to 29.2 per cent during 1975—79, to 38.3 per cent during 1980—1983. These trends suggest that something significant has occured in the UK SMF sector, at least as far as national innovation share is concerned. The marked decrease in innovation share taken by firms in the 1000—9999 size category appears to be partly the result of structural industrial shifts resulting from takeover and merger activity and partly due to a decline in relative innovative efficiency (see below).

Because a firm is very large, this does not necessarily mean that the *unit* producing the innovation is very large also. Table I gives time

	Small firms	Large firms
Marketing	Ability to react quickly to keep abreast of fast changing market requirements. (Market start-up abroad can be prohibitively costly.)	Comprehensive distribution and servicing facilities. High degree of market power with existing products.
Management	Lack of bureaucracy. Dynamic, entrepreneurial managers react quickly to take advantage of new opportunities and are willing to accept risk.	Professional managers able to control complex organisations and establish corporate strategies. (Can suffer an excess of bureaucracy. Often controlled by accountants who can be risk-averse. Managers can become mere 'administrators' who lack dynamism with respect to new long-term opportunities.)
Internal	Efficient and informal internal communication networks. Affords a fast response to internal problem solving; provides ability to reorganise rapidly to adapt to change in the external environment.	(Internal communications often cumbersome; this can lead to slow reaction to external threats and opportunities.)
Qualified technical manpower	(Often lack suitably qualified technical specialists. Often unable to support a formal R&D effort on an appreciable scale.)	Ability to attract highly skilled technical specialists. Can support the establishment of a large R&D laboratory.
External communications	(Often lack the time or resources to identify and use important external sources of scientific and technological expertise.)	Able to 'plug-in' to external sources of scientific and technological expertise. Can afford library and information services. Can subcontract R&D to specialist centres of expertise. Can buy crucial technical information and technology.
Finance	(Can experience great difficulty in attracting capital, especially risk capital. Innovation can represent a disproportionately large finanical risk. Inability to spread risk over a portfolio of projects.)	Ability to borrow on capital market. Ability to spread risk over a portfolio of projects. Better able to fund diversification into new technologies and new markets.
Economics of scale and the systems approach	(In some areas scale economies form substantial entry barrier to small firms. Inability to offer integrated product lines or systems.)	Ability to gain scale economies in R&D, production and marketing. Ability to offer a range of complementary products. Ability to bid for large turnkey projects.
Growth	(Can experience difficulty in acquiring external capital necessary for rapid growth. Entrepreneurial managers sometimes unable to cope with increasingly complex organisations.)	Ability to finance expansion of production base. Ability to fund growth via diversification and acquisition.
Patents	(Can experience problems in coping with the patent system. Cannot afford time or costs involved in patent litigation.)	Ability to employ patent specialists. Can afford to litigate to defend patents against infringement.
Government regulations	(Often cannot cope with complex regulations. Unit costs of compliance for small firms often high.)	Ability to fund legal services to cope with complex regulatory requirements. Can spread regulatory costs. Able to fund R&D necessary for compliance.

Note: The statements in parentheses represent areas of potential *disadvantage*. Abstracted from Rothwell and Zegveld (1982).
Source. R. Rothwell, 'Innovation and Firm Size: A Case for Dynamic Complementarity', *Journal of General Management* **8**(3), Spring 1983.

Fig. 1. Advantages and disadvantages of small and large firms in innovation.

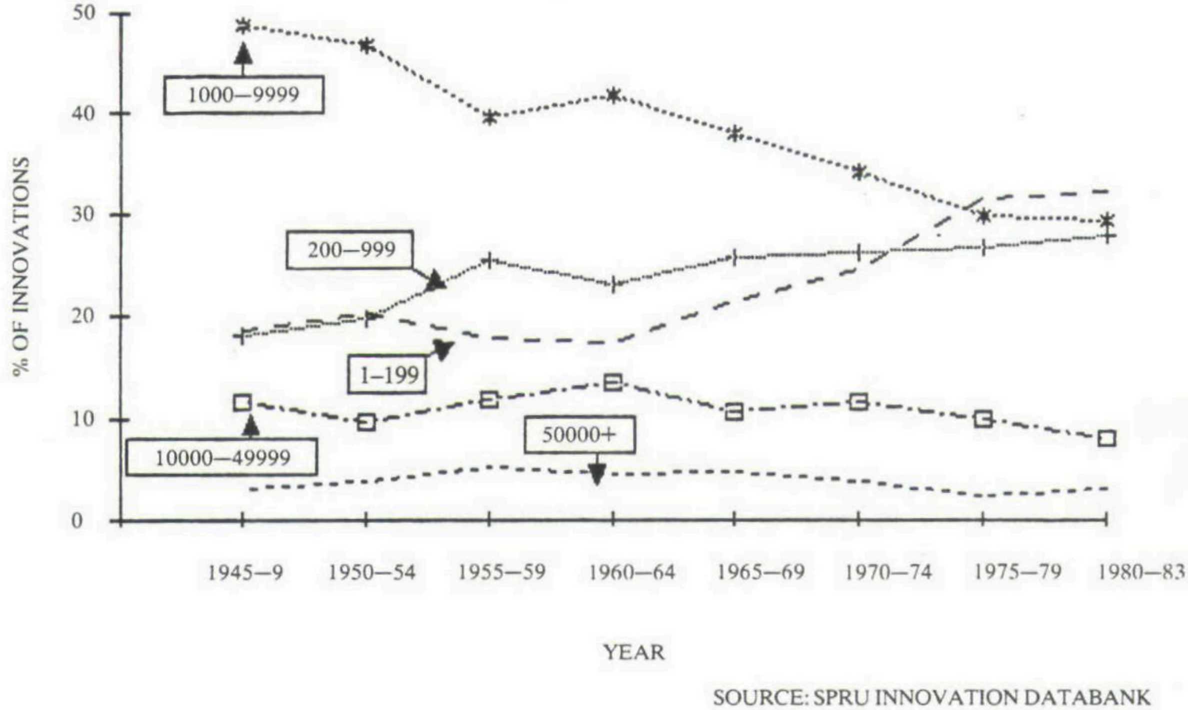


Fig. 2. Trends in the size distribution of innovative firms (%) 1945—83 (unit employment in boxes).

TABLE I
Innovation share by size of innovating unit in the UK, 1945—83.

Time period	*Size of innovating unit* 1—199	200—499	500—999	1000—9999	10 000—29 000	30 000—99 999	100 000+	No. of innov's
1945—49	18.6	9.3	8.8	48.7	11.5	0.9	2.2	226
1950—54	20.1	13.6	6.1	46.8	9.2	2.8	1.4	514
1955—59	17.9	14.0	11.5	39.7	11.9	2.7	2.3	514
1960—64	17.4	12.7	10.2	41.8	11.7	3.4	2.8	684
1965—69	21.4	14.2	11.4	37.9	9.2	3.3	2.6	720
1970—74	24.5	14.0	12.2	34.0	10.1	2.9	2.3	656
1975—79	31.3	13.6	13.0	29.8	8.3	2.7	1.3	823
1980—83	32.1	17.7	10.1	29.3	6.8	2.8	1.3	396
Number of innovations	1025	605	480	1625	427	125	91	4387
Average percentage	23.4	13.8	11.0	37.1	9.8	2.9	2.1	100

series data for innovation share not by size of firm, but by size of *innovating unit*, i.e. subsidiary, division, etc. This illustrates a marked shift in innovation share towards small and medium-sized units (SMUs), from 27.9 per cent during 1945—49 to 49.8 per cent during 1980—83. As figure 3 shows, this change was associated with an increased share of innovations taken by subsidiary companies between about 1955 and 1975, following which independent companies — mainly small and medium-sized firms — increased their share considerably and the share deriving from public sector institutions and firms' divisions declined significantly. To some extent at least, the above pattern might reflect attempts on the part of large companies to marry the resource-related advantages of large firms to the behavioural advantages of smaller firms. The SPRU data do indicate that large firms have tended to acquire smaller firms to facilitate their movement into new areas of activity. In other words, large firms have frequently diversified through a process of small firm acquisition.

As might be expected, the contribution of small

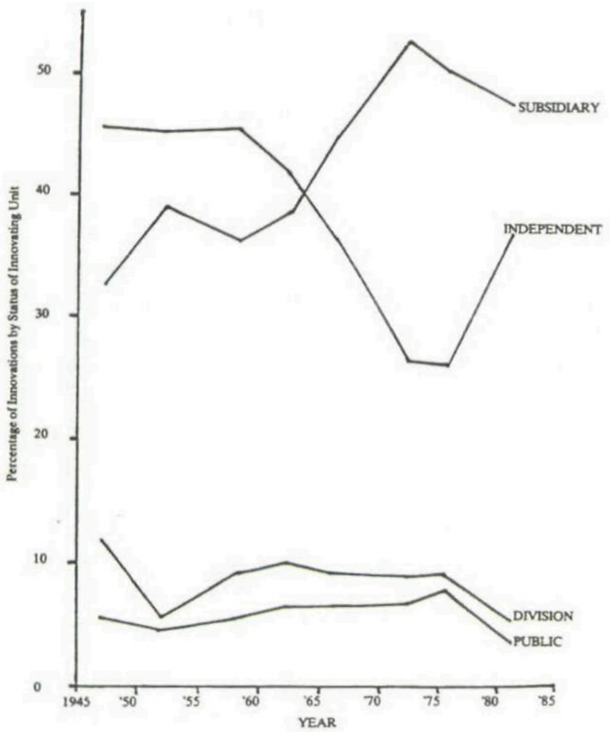


Fig. 3. Innovation share by status of innovating unit.

firms to innovation varies considerably between sectors of industry. In areas such as aerospace, motor vehicles, dyes, pharmaceuticals and shipbuilding, small firms' innovation share has been only small. In areas such as scientific instruments and specialist machinery, small firms' innovation share has been significant and growing. In general, where capital and/or R&D requirements and entry costs are high, small firms' share has been small, and vice versa.

The case of electronic computers is interesting since it illustrates clearly the necessity for adopting a *dynamic* approach to the question of firm size and innovation. For most of the period up to 1970, SMFs' share of innovations in this area was relatively small or zero.

Between 1970 and 1983, however, SMFs' share increased dramatically from 36% during 1970—74, to 47% during 1975—79, to 64% during 1980—83. During the 1950s and the 1960s UK production was composed almost entirely of mainframe computers with associated high R&D, manufacturing and servicing costs, which effectively debarred SMF participation on an appreciable scale. With the introduction of the integrated circuit and more significantly of the microprocessor , entry by SMFs became entirely possible, and they rapidly became involved in the production of mini and micro-computers and peripherals to satisfy the many new market segments that emerged. The rapidly developing field of biotechnology might similarly open up niche opportunities for SMFs in pharmaceuticals and related areas. Thus while one type of technology might effectively prevent significant participation by SMFs, another can present them with many new product-market opportunities.

Freeman (1982) has compared the SPRU innovation data with data obtained by Kleinman (1975) in the United States; his results are shown in Table II. Taking the aggregated figures, the firm size distribution of innovations in the two countries is remarkably similar, but with "smaller" US companies taking a greater innovation share than their UK counterparts.

Simply counting innovation shares, of course, tells us nothing about the relatively innovative efficiency of firms of different sizes measured as innovations per unit of employment; nor does it

TABLE II
The size distribution of innovations: UK and US samples compared by percentages of total

Sector		Size of firm by employment 1–999	1000–9999	10 000 and over	Number of innovations
Chemicals	UK	9.0	7.6	83.3	288
	US	13.1	7.5	79.4	107
Machinery	UK	37.2	41.3	21.5	460
	US	50.0	26.6	23.4	64
Electronic products	UK	17.4	11.6	71.1	242
	US	40.0	40.9	19.1	115
Instruments	UK	55.4	24.6	20.0	195
	US	56.9	24.2	19.0	211
Electrical products	UK	25.9	25.9	48.2	81
	US	15.8	12.0	72.3	184
Motor vehicles and other transport	UK	5.3	34.9	59.8	152
	US	7.9	5.3	86.8	38
Total of samples	UK	25.0	22.8	52.2	2293
	US	30.5	17.7	51.7	862

Notes. Sectoral breakdowns are according to the innovating firm's principal activity. The sum of the sectors is less than the total as not all sample was included in this comparion.
Source: C. Freeman, 1982.

provide any indication of relative R and D efficiency measured as innovations per unit of R and D expenditure. This issue has been dealt with in some detail by Wyatt (1984), whose results will be only briefly summarized here.

Utilizing the SPRU innovation data and employment statistics published by the UK Business Statistics Office, Wyatt has derived time series data on the ratio, innovation share/employment share, for firms in five employment categories. This analysis, using aggregated data, shows:

— An increase over time in the relative innovative efficiency of firms with employment between 1 and 199, from 0.46 in 1955—59 to 0.53 in 1975—80.
— An increase over time in the relative innovative efficiency of firms with employment between 200 and 499, from 0.66 in 1955—59 to 0.82 in 1975—80.
— A decrease over time in relative innovative efficiency of firms with employment between 500 and 999, from 0.76 in 1955—59 to 0.46 in 1975—80.
— A more marked decrease over time in the relative innovative efficiency of firms with employment between 1000 and 9999 from 0.83 in 1955—59 to 0.45 in 1975—80.
— A consistently greater than unity relative innovative efficiency of firms with employment greater than 10 000 e.g. a ratio of 2.02 in 1955—59 and a ratio of 1.91 in 1975—80.

On the basis of these data, Wyatt concludes that the fact that firms with employment less than 500 have maintained their share of British innovations more successfully than those with employment between 500 and 10 000 reflects not only structural industrial shifts, but also changing patterns of innovative efficiency. While the aggregate data indicate that it is firms in the largest size category that have attained the highest levels of relative innovative efficiency, the disaggregated data, as we might expect, indicate considerable variation between sectors, and small firms show relative innovative efficiency levels of greater than unity in plastics, textile machinery, mining machinery, radio, radar and electronics capital goods and scientific instruments.

Turning to relative R and D efficiency of innovation, Wyatt's data paint a rather different picture. In 1975, firms with employment between

100—499 enjoyed two per cent of total national manufacturing R and D expenditure; between 1969 and 1980, they produced 20.6 per cent of total innovations, yielding a relative R and D efficiency ratio of 10.3. The comparable figures for firms in the largest size category (employment greater than 10 000) are 80 per cent and 43.3 per cent respectively, yielding a relative R and D efficency ratio of 0.54. Thus on the basis of these data, R and D efficiency is very much higher in the smaller firms. A possible explanation of this, and one favoured by Wyatt, is that there is a lower degree of functional specialization in small firms with a higher proportion of innovative activities occurring outside of what is formally defined as R and D, a point emphasized by Segal and Quince (1985) in their study of new small firms in Cambridge. This would imply, however, that the informal R and D performed in small firms is very considerable indeed. For example, even if we ascribe a 20 per cent share of toal R and D to the smaller firms — a factor of ten increase — their relative R and D efficiency would still be almost double that of the largest firms. Whatever the case, given the overwhelming concentration of R and D resources in the largest sized firms, it is hardly surprising that they have produced the bulk of British innovation. From the viewpoint of the health of the small firm sector in Britain, perhaps the most promising feature is the increasing innovative efficiency of SMFs; given their relative lack of R and D resources, they have performed remarkably well.

3. The role of small firms in the emergence of new industry sectors[1]

Up to this point we have dealt largely with the role of small firms in introducing new product innovations. Below we shall adopt a more dynamic view and describe the role that NTBFs have played in the emergence of two new technologies and new industrial sectors based on these technologies.

The evolution of the US semiconductor industry

The beginnings of the semiconductor industry can be traced to the invention of the transistor effect in Bell Telephone Laboratories in 1947 by Bardeen and Brattain. Although their findings paved the way for the invention of the bipolar junction transistor, the real breakthrough came in 1952 when Shockley, the research team leader, described a field effect transistor with a central electrode consisting of a reverse-biased junction. Shockley subsequently left Bell Labs and several years later he established his own company in his native Palo Alto, *backed by finance from the Clevite Corporation.* Shockley attracted a number of leading physicists and engineers into his company but, in 1957, eight of his brightest people left to form their own company. This marked the beginning of the rapid growth of new technology-based firms in the Palo Alto area, which subsequently gave it its name of Silicon Valley. While a number of other centres of semiconductor production were emerging concurrently notably at Dallas, Texas (Texas Instruments) and Phoenix, Arizona (Motorola), nevertheless it is true that Silicon Valley has been the exception in world terms in the amount of semiconductor production and technological innovation that has occurred in such a concentrated area.

The eight ex-Shockley workers *succeeded in obtaining backing from the Fairchild Camera Corporation*, which had been actively seeking diversification, and, in September 1957, Fairchild Semiconductor was founded in Mountain View, California. In 1959, Fairchild Camera Corporation exercised an option to buy a majority interest in Fairchild Semiconductor. The latter grew rapidly from sales of $0.5 million in 1960 to $27 million in 1967 to $520 million in 1978.

During the next few years there was considerable spin-off from Fairchild Semiconductor of both people and technology, and many companies were formed by people formerly with, or associated with Fairchild. This process has been describd by Mason (1979):

> . . . The first spin-off was in 1959, when Baldwin, not from the original Shockley team, left Fairchild to form Rheem Semiconductor, *collecting on the way people from Hughes Aircraft.* In 1961, four of the originals left to form Amelco and one of these, Hoeni, left in 1964 to form Union Carbide Electronics; moving on in 1967 to form Intersil. Of . . . interest . . . was another event in 1961, when Signetics was formed. This was formed by four people who were a significant part of the Fairchild Semiconductor team. . . . *They managed to get venture capital backing from the Dow-Corning group for this move.*

At the same time that new technology-based small firms were being spawned in Silicon Valley, Bell Labs. (a subsidiary of AT&T), continued with its vigorous inventive and innovative activity, although all AT&T output (via Western Electric) was produced for its own use in order to avoid anti-trust litigation. Bell Labs., along with other major companies have, between them, *accounted for a high percentage of all major innovations in semiconductor technology*.[2] Interestingly, since 1976, major Japanese companies have made an increasing contribution to technological advance in semi-conductors: Sharp's automatic bonding on 'exotic' substrates in 1977; Mitsubishi's vertical injection logic and V-MOS in 1978; Fujitsu's 64-K bit in 1978 (Dosi, 1981).

Despite the initial dominance of large companies in basic invention in the semiconductor field, new technology-based small firms played a key role in commercial exploitation, especially during the earlier stages in the US semiconductor industry's development.

What in fact occurred during the evolution of the US semiconductor industry was a classical example of the *dynamic complementarities* that can exist between large and small firms. Existing large firms provided much of the basic, state-of-the-art technology, venture capital and technically skilled personnel which were essential to new technology-based firm start-up; the new technology-based firms provided the risk-taking entrepreneurial drive and rapid market exploitation.

From the late 1960s onwards, the output of the US semiconductor industry began increasingly to be concentrated in the top ten or so companies. Production economies of scale grew in importance (and plant size increased), as did production learning, and firms began actively to seek rapid movement down the production learning curve. The importance of price in competition increased as the unit cost of semiconductor component production decreased. According to Sciberras (1977), the prime motive for rapid cost reductions was to deter new entrants by creating significant scale barriers to entry in addition to technological entry barriers. This might at least partially explain why semiconductor technology was exploited in Europe by large existing electronics companies: Europe entered the race at a late date, by which time existing scale and technological barriers largely precluded entry by new small firms.

Thus, in the development of the US semiconductor industry, we see an example of Schumpeterian industrial evolution from the "entrepreneurial" model of the newly emerging industry, to the "managed" model of the mature international ologopoly of today. Nowadays, the main opportunities for new entrants appear to be not in semiconductor production itself, but rather in the application of semiconductor devices to the production of new products, notably in the general area of "information technology", currently mooted as the 'new' industry of the next decade.

The evolution of the computer aided design industry

A second example of industrial evolution that indicates an important role for NTBFs can be found in the case of the computer aided design (CAD) industry. The data below are drawn from the work of Kaplinsky (1981, 1982), who has identified four main phases in the development of the CAD industry: pre-1969 (industry origins); 1969—1974 (dynamic new firms); 1974—1980 (the trend to concentration); post 1980 (maturity).

During the first phase development was concentrated in established large companies in the defence, aerospace and aeronautical industries in collaboration with mainframe computer manufacturers, and in the late 1960s General Motors entered the field with the development of its 'Design Augmented by Computers" programme.

> In summary, therefore, during this early period there was hardly any 'market" for CAD, with most developments occurring to assist own-use by large, technically advanced engineering corporations in the US and (to a lesser extent) in the UK (Kaplinsky, 1981).

The second phase was charcterised by the emergence of the new small spin-off firms in the US (from both CAD producers and electronics companies) which played the primary role in the rapid diffusion of CAD devices into the electronics industry. Several of these firms grew extremely rapidly to become, along with IBM, today's market leaders. In Europe, in contrast, the major existing electronics firms developed CAD equipment for their own use.

> In summary, therefore, this second period of industry development saw the emergence of new, independent firms and the rapid diffusion of the technology out of the defence, aerospace and automobile sectors to the electronic sectors (Kaplinsky, 1981).

The third phase saw the rapid diffusion in use of CAD across manufacturing, a process in which the 'newcomers' played a key role. During this period of extremely rapid market growth, the industry became increasingly concentrated, 93 per cent of US market share in 1980 being held by eight companies and most notably Computervision with 33.2 per cent of the total. At the same time patterns of ownership began to change and there was a series of takeovers by major corporations of several of the fast-growing newcomers.

> To summarise, therefore, this third phase of industry development was associated with the growing size of CAD firms, the growing organic trend towards concentration within the sector, and a tendency for formerly independent CAD firms to be swallowed by existing trans-national corporations (Kaplinsky, 1981).

At the beginning of the fourth phase in development, the market was dominated by turnkey suppliers supplying either mainframe systems (user entry costs of about $500 000) or minicomputer systems (user entry costs of about $200 000). From 1980 onwards, as the user base has broadened, a market niche has emerged for dedicated systems. These are based not on a comprehensive and flexible package of software applications, but on limited software packages for specific applications. A number of micro-computer based companies, founded by spin-offs from existing CAD suppliers, and using 'mature' application programmes developed by these suppliers, have begun to emerge, offering systems for as little as $30 000 each.

> To summarise, therefore, this most recent stage of industry development has seen two divergent trends — a continued tendency to concentration and an opposing tendency for the entry of new small firms selling limited capability dedicated systems (Kaplinsky, 1981).

In the UK, it has been estimated that US firms held a 62 per cent share of all CAD systems installed up to mid-1981. Of the remaining 38 per cent share of installations, 17 per cent were held by subsidiaries of large electronic companies established in the late 1960s, 12 per cent by spin-off companies, 5 per cent by a public body (essentially a software house) and 4 per cent by other companies.

From the above brief descriptions of the evolution of two high-technology industries we can draw out a number of significant factors:

- Established large US corporations played a crucial initiating role in invention and innovation both in semiconductors and CAD technology. In both instances the early inventive and innovative activity was geared towards 'own use'.
- In the case of semiconductors, much of the dynamic growth and *market diffusion* came about as a result of the formation and rapid expansion of NTBFs.
- In the CAD industry, NTBFs similarly played the key role in the rapid *diffusion* of CAD systems to electronics and other areas.
- In both cases, the technological entrepreneurs often came from established corporations, bringing a great deal of technological and applications know-how with them.
- In both cases, established corporations and venture capital institutions played an important part in funding the start-up and growth of NTBFs.
- In both cases, the industries rather quickly became highly concentrated and the subject to external takeover.
- In both cases, as the industries matured, scale economies[3] became increasingly important in the mainstream activities and strong oligopolies were formed, leaving only specialist market niches for new and small suppliers.

It is clear from the description of the evolution of the semiconductor and CAD industries that it is necessary to consider the *interactions* between small and large firms if we are fully to understand the evolutionary dynamic of technologies and industrial sectors. In both instances existing large corporations played the major initial role in invention, producing new devices largely for in-house

use only. The major role in the initial rapid market diffusion of these new devices, however, was played by new, small but fast growing companies founded by technological entrepreneurs. Moreover, the technical know-how, the venture capital and the entrepreneurs themselves very often derived from the established corporations, as well as, in the case of the latter two, from major companies operating in other areas. A spin-off firm appeared to be the most suitable organisation form for types of innovation where (the application of) new technologies are involved. Thus we see a system of dynamic complementarity between the large and the small: both had their unique contribution to make; both were necessary, the former to the initiation of the new technological paradigm, the latter to rapid market diffusion and general commercial exploitation.

What the above discussion does suggest is that established technology-based large corporations can be extremely effective in creating new technological possibilities; they are highly inventive. While they are adept at utilising the results of their inventiveness in-house (*new* technology for *existing* applications), they are less well adapted to the rapid expoitation of their inventions in new markets (*new* technology for *new* applications). It appears that new firms, initially, are better adapted to exploit new techno-market regimes, breaking out from existing regimes within which established corporations, for historical, cultural, regulatory and institutional reasons, might be rather strongly bound. Referring back to the discussion of innovatory advantage and disadvantage, it appears that during the early phases in the evolution of a new industry (assuming, of course, that entry costs are not too high) the behavioural advantages of small scale are crucial to commercialization and diffusion; as the industry evolves, technological possibilities become better defined and market needs become increasingly well specified, the advantages of large scale begin to dominate. Comparative advantage shifts to the larger firms and the industry develops towards a mature oligopoly, a situation characteristic of the semi-conductor and CAD industries today.

4. NTBFs in Europe

In contrast to the situation in the United States, up to the early 1980s NTBFs appear to have played only a limited role in the economies of Europe. This point is supported by the data provided in Table III, which are taken from a study undertaken by the Arthur D. Little organisation in 1977. The A. D. Little study set out to determine the number of NTFBs founded between 1950 and 1975 in the UK and the FRG that were still in existence in 1975, and to assess their economic impact. As the data show, both the number of

TABLE III
NTBFs: Europe — 1950—1975.

A. D. Little study (1977): NTBFs in the UK and the FRG, 1950—1975

	UK	FRG
Number in existence:	200	100
	(considered only manufacturing — probably an underestimate)	
Total employment:	15 000	12 000
Total annual sales (1985):	£200 Million (50= from 4 companies)	£180 Million (60% from one company — Nixdorf)
Export ratio:	30%	—
Sectors: mainly electrical and electronic.		

TABLE IV
NTBFs in Europe: 1970—1985.

Segal Quince and ISI institute study (1986)			
	UK	FRG	
Number in existence:	6—7000	3000	
Start-up rate:	"Explosive" since the mid-1970s Most are "very young" — post-1979	Mid-1970s: 40—60 per annum 1983: 125	
Employment (1985)	About 120 000	About 120 000	
Sectors:	Electronics Computer hardware and software; instruments; (recently) biotechnology	Electronics and telecomms Computer hard & soft Sci. instruments	50% 17% 16%
Strong geographical clustering effects in both countries.			

firms and their economic contribution were small. A more recent study conducted by Segal, Quince, and Wicksteed in the UK and the ISI Institute in the FRG produced startlingly different results (Segal, Quince, and Wickstead, 1986); their results are shown in Table IV. The data indicate a massive increase in the number of NTFBs (including software companies) in both countries. Annual NTBF start-up rates have been increasing rapidly since 1979, and a recent estimate puts the number of NTBFs founded in the FRG in 1986 at nearly 500 (Corsten, 1987). It remains to be seen, however, whether a significant percentage of these companies will achieve the remarkable growth rates enjoyed by US companies such as Computervision and Fairchild Semiconductor.

Amongst the reasons underlying the growth in number of European NTBFs are:

— the nature of several of the emerging "technology clusters" (see Table V); in the information technology area in particular, entry costs for new firms are relatively low; innovation is knowledge intensive rather than capital or scale intensive, and IT has opened up many new market niches suitable for small firm entry;

TABLE V
Emerging technology clusters

Biotechnology	single cell protein bio-engineering biomass diagnostic kits pharmaceuticals
Energy technologies	heat pumps solar energy devices coal gasification and liquefaction renewable energy sources monitoring and control equipment
Advanced materials technology	biocompatible materials (implants) advanced composite material advanced electronics materials superconducting materials
Information technologies	electronic office equipment fibre optic systems satellite communications scientific and medical instruments advanced computing software developments I.T. in the home etc. etc. etc. (I.T. for existing and new applications)

- the growth in Europe venture capital: up to about 1980, venture capital in Europe was extremely sparce; since 1980, partly as a result of public policy initiatives (Rothwell, 1985) and partly as a result of changing attitudes on the party of previously conservative financial institutions, venture capital has grown rapidly;
- more favourable social and political climates;
- increased entrepreneurial tendencies on the part of academics.
- displacement effects brought about by firm closures and companies' rationalisation activities.

The new entrepreneurial spirit in Europe is well exemplified in the UK by the Government's attempts to create an "enterprise culture", reducing attitudes of dependency on the State and lauding the virtues of enterprise and self reliance. The "single market" planned for the European Community in 1992, creating the largest single free market in the world, will, it is hoped, further stimulate the creation and growth of NTBFs in Europe.

A recent study of a small number of highly innovative SMFs in Europe clearly indicated the potential economic contribution such firms can make (Dodgson and Rothwell, 1987). The research looked at 12 leading edge, niche-strategy SMS in three countries. In 1985 the 12 firms between them employed 4000 and had a combined turnover of 322 million ECU. Between 1983 and 1985, the average rate of employment growth was 20 per cent and in turnover it was 127 per cent. The firms were all highly export-oriented with an average export orientation of 68 per cent. Not all the firms were NTBFs: three were established before 1920; four between 1950 and 1970 and five after 1970. The study clearly illustrated that even long-established firms can achieve renewed levels of high performance if they adopt the appropriate techno-market strategies based on in-house technological accumulation coupled to a strong market orientation. They all operated at the forefront if their respective technologies and their average R&D expenditure as a percentage of sales was 12.4. All had vigorous policies of complementing their in-house technical resources with external expertise from infrastructural institutions

5. Summary

(i) Innovatory advantage is unequivocally associated with *neither* large *nor* small size.

(ii) Small firms' advantages are seen to be mainly *behavioral*, while these of large firms are seen to be mainly *material*.

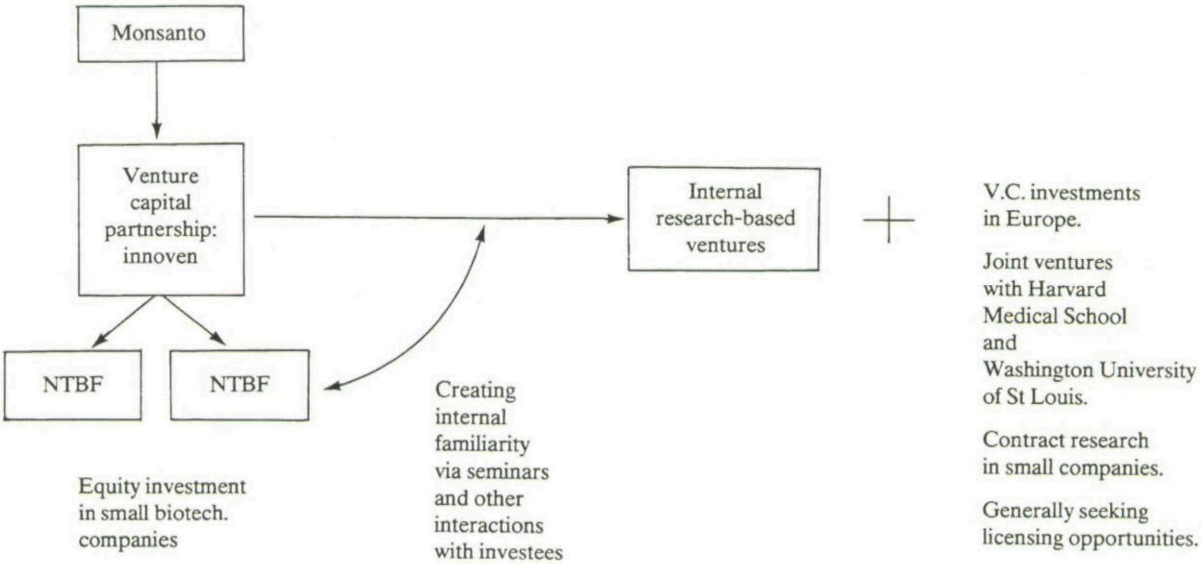
(iii) NTBFs appear, since 1980, to be playing an increasingly important role in the economies of Europe.

(iv) The main factors contributing to increased NTBF activity are: the nature of emerging technologies; growth in venture capital; and the emergence of a new entrepreneurial spirit in Europe.

(v) Small and large firms do not exist in isolation from one another. In the case of the US semiconductor and CAD industries, both small and large firms played important, but different, roles in the dynamic of industrial growth.

(vi) Any study of the roles of small and large firms in industrial innovation and growth should be dynamic; their relative roles might vary considerably over the industry cycle.

Finally, the latter two points can be further illustrated by considering the recent growth of the "new" biotechnology industry. In this case, basic inventive activity has occurred mainly in small, new companies which were generally spin-offs from university departments performing state-of-the-art research. Increasingly, large chemical and pharmaceutical firms have invested in, bought-out, or formed joint ventures with these NTBFs, which they see as a crucial technological resource. This process is illustrated in Figure 4, which outlines Monsanto's strategy for entry into the biotechnology field. Monsanto utilised venture capital investments as a means of gaining know-how in biotechnology prior to initiating internal R&D ventures, and it has continued to expand its R&D contacts with small companies. What we are observing is a new large/small firm dynamic in which small firms provide state-of-the-art technical expertise to large firms which in turn have the resources for development, manufacturing and marketing and the know-how and resources to handle stringent and costly regulatory requirements. This system of large/small firm complementarity further empha-



Source: Derived from Roberts and Berry, 1985.

Fig. 4. Monsanto: Entry strategy to biotechnology field.

sises the need to look not only at large firms *or* small firms, but in addition to look at the relationships between them.

Notes

[1] This section is taken from R. Rothwell, 1983; and Rothwell and Zegveld, 1985.

[2] In excess of 60 percent of all major innovations introduced between 1951 and 1971 (Webbink, 1977).

[3] In the case of CAD, the most significant scale economy has been accumulated software expertise, i.e. the size of the knowledge base is a very much more significant barrier to entry than manufacturing capacity.

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