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Science-based industries: a new Schumpeterian taxonomy

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Abstract

Science-based industries (SBIs) are the fastest-growing sector of the knowledge economy. SBIs have been categorized in traditional Schumpeterian typologies that are unable to explain their many differing industrial dynamics. However, new concepts already exist to improve our understanding of SBIs, including many coming from evolutionary theories (such as technological trajectories, path dependence, lock-in, self-reinforcing mechanisms, etc.), to develop the main theoretical issues, including a new typology, of these industries. Such is the goal of this paper.

1. Introduction

Science-based industries (SBIs) are the fastest-growing segment of the knowledge economy. Their growth and internal characteristics challenge the established concepts of industrial economics and management through which we understand more traditional industries. In this paper, the different industrial dynamics are underlined (Section 2), the evolutionary debates on industry structure are recalled (Section 3) and a new typology is proposed to understand these industries (Section 4). An explanatory model is then proposed (Section 5). In addition to the classical Schumpeterian dichotomy, it suggests two new types of science-based industries that probably represent the foundation on which a new theoretical paradigm is now emerging. The conclusion underlines the fact that Schumpeter Mark I and II do not adequately describe and explain the existing dynamics of science-based industries that can be best analyzed with the help of an evolutionary framework.

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2. The problem: widely different industrial dynamics

Science-based industries are the core of the knowledge economy. They are not easily framed within previous categorizations and models, including many inspired by the Schumpeterian industrial economics tradition. This is because they show widely different patterns of technical change and economic dynamics.

Industries differ in their patterns of technical change. Keith Pavitt has suggested, more specifically, that they vary in their sources of technology, requirements of users and appropriation mechanisms, and proposed a typology [1]. In *supplier-dominated activities* (such as agriculture, building, mining, forestry, commerce, and traditional manufacturing) most innovations come from suppliers of equipment and materials. Firms operating in these activities undertake little R&D and request few patents. In *production-intensive activities* (such as scale-intensive industries including cement and glass manufacturing, metal refining, and transportation equipment, and specialized suppliers such as machinery production), R&D is conducted in the larger firms. It is centered on both product and process technologies, according to the specific activity. Process innovations are more often protected by means of secrecy, and product innovations are protected through patents.

Within *science-based industries*, the main source of technology is in the R&D activities of the firms. This R&D is based on the development of science, in universities and in public laboratories, with which these firms entertain close collaboration. These industries include electrical equipment manufacturing, fine chemicals (including pharmaceuticals and biotechnology), aircraft and aerospace, electronics, optical and laser instruments, robotics, and advanced materials. SBIs are more prone to “technology push” innovation, arising from in-house R&D, which is ubiquitous, regardless of the size of the firm. Novelty is protected through patents, secrecy and speed of innovation.

The problem is that science-based industries are by no means a homogeneous group (see Table 1). Some of them are very old and rather mature, having developed over a century, such as aircraft and heavy electrical equipment; some are very new, such as computer software and biotechnology. Some of them have started as very concentrated industries, such as the production of missiles, and have remained as such for all their life cycle, while others have started as entrepreneurial industries with many firms and concentrated later, such as the pharmaceutical and the computer software industries. The R&D intensity of such industries varies widely, as do barriers to entry.

3. Evolutionary analysis of industrial dynamics

Several competing evolutionary models have tried to explain industrial dynamics. All of them share a few major concepts. These include those of increasing returns to scale, path dependency, self-reinforcing mechanisms, variety, technological and organizational trajectories and creative destruction. These evolutionary concepts offer

Table 1
Some characteristics of major SBIs in the global economy

Industry	Number of years industry established	Number of firms as of 1998	Type of market	World sales 1997 (US$)	R&D/Sales (%)	World leader by sales as of 1997
Aircraft (commercial)	80	10–20	Oligopoly	ND	4 (1)	Boeing (US)
Biotechnology	22	>2500	Dispersed	13 bn	54 (4)	Amgen (US)
Office, computers and accounting machines	50	>100	Niche oligopolies	ND	9.7 (2)	IBM (US)
Memory chips (DRAMs)	50	>100	Oligopoly	21 bn	ND	Samsung (Korea)
Microprocessors and digital signal processors	27	<10	Oligopoly	49 bn	9.4 (3)	Intel (US)
Medicines and drugs	120	>1000	Oligopoly	300 bn	12.1 (2)	Glaxo-Wellcome (UK)
Missiles and aircraft	60	<10	Oligopoly	ND	5.2 (2)	Arianespace (Europe)
Software	30	>10000	Dispersed	122 bn	16.5 (5)	Microsoft (US)
Communications equipment	100	>1000	Oligopoly	211 bn	9.3 (2)	Lucent (US)

Notes. (1) Based on the figures published by Boeing and Bombardier (world's first and third producers). Airbus does not release such figures. (2) US figures for 1993 [35]. (3) 1997 figures for Intel (source:). (4) US data for 1995 [36]. (5) Data for Microsoft for 1996 [37].

a unique perspective for the development of the analysis of science-based industries, and the improvement of the Schumpeterian analysis of industrial dynamics.

3.1. Increasing returns

Increasing returns to scale is an "analytical inconvenient" assumption in neoclassical economics [2]. For perfect competition to exist, marginal costs should rise when the firm's output is still small relative to the whole industry. Also, falling or at least stagnating demand would check the growth of the firm. Under increasing returns the firm would grow without limits towards monopoly, and the perfect competition assumption would then need to be abandoned. This is why few authors in the past elaborated their theory on the basis of increasing returns.

In science-based industries, there are at least two major factors explaining the predominance of increasing returns [3]. One is R&D and knowledge production, an activity where economies of scale are generalized: it suffices to produce any innovation once, and then exploit it through the largest production across the globe to best reap the benefits of the novelty. R&D is a major component of total cost in science-based industries, and firms active in these tend to distribute these costs over the biggest feasible output. The second factor is economies of scale in marketing. In most science-based industries, the market is often large and fast growing, and economies of scale in marketing are well known.

The first casualty of the assumption of increasing returns is general equilibrium [4]. In industries characterized by increasing returns, movements out of equilibrium are normal and permanent. Creative and dynamic destruction is the norm. The second and most important theoretical novelty is that economic changes are endogenous. ". . . With increasing returns 'change becomes progressive and propagates itself in a cumulative way'" [4: 1244]. Kaldor suggests that cumulative processes, as discovered and analyzed by Myrdal, are regular features of the economy. In science-based industries, cumulative processes are common, both at the level of the firm and within larger aggregates. Knowledge and learning are typically cumulative and localized [5,6] as firms tend to explore the areas they know better.

3.2. Dynamic competition

Another characteristic related to increased returns is that under permanent innovation, competition becomes sequential rather than concurrent [2]. Dominant firms are replaced by new competitors with innovative products: the personal computer revolution brought new firms into the computer industry that dislodged IBM's mainframe from its dominant position in computers. These commanding positions are sustained through rapid innovation, as well as patent protection, a frequent situation in the pharmaceutical industry.

Innovation thus explains why new firms enter a market in which a large firm has already captured a dominant position. Challengers expect to develop the following generation of products and thrive on the lock-in mechanisms created by asset specificity of existing market leaders. In SBIs, competition is better characterized by creative destruction and turnover among the top contenders than as an automatic and peaceful process of adjustment of output and prices among thousands of small firms under perfect competition.

Due to bounded rationality and positive information costs, as well as asset specificity (such as past investment in existing software or knowledge about existing drugs), more performing products gain market share slowly, and several products compete displaying sometimes very different levels of performance [7]. A durable monopolistic position is thus rarely achieved in science-based industries; temporary monopolies and oligopolies based on first-movers' advantages are far more common market situations [8,9]. In such situations, the dispersion of firms (in terms of size, profits and performance) is very high; there is no such thing as a representative firm, a normal profit or a typical behaviour. Variety is the dominant characteristic of an industry. These industries are not tending towards equilibrium, or a steady state, but continuously moving forward, incorporating new products, new processes, and experiencing turnover among firms. Competition, but a dynamic one, coexists with increasing returns and temporary monopolies and oligopolies.

3.3. *Path dependence*

Path dependence is a dynamic characteristic of allocative non-ergodic processes [10]. Non-ergodic processes are those that move within a predetermined set of states; the motion among these states is governed by probabilities that can be known. Conversely, if a system can move freely from one state to another, the system is ergodic and not path dependent. Paul David [10] and W. Brian Arthur [3] suggest that economic processes are typically non-ergodic. In a world of perfectly rational economic agents and instantaneous adjustment without asset specificity, the observer cannot predict the future action of firms. The neoclassical world of economics is an ergodic one. On the contrary, if agents are afflicted by bounded rationality with its associated myopia, and asset specificity, their range of alternatives is reduced, usually to technical and organizational choices which are close to the existing capabilities, physical assets and knowledge stocks of the firm. In other words, future choices are restricted by past choices. History affects the choices of economic agents. Also, in a world of bounded rational agents that tend to satisfy, not to maximize, best choices are usually local optima; under new conditions (for example enlarged markets, new applications for existing products), but under asset specificity, these local optima may become locked-in second-rate solutions. Nonetheless, in SBIs, where high levels of R&D and rapid innovation are the norm, there are higher chances than in traditional industries that these second-rate solutions are selected out by new products from the market, with or without the arrival of new entrants.

3.4. *Variety*

In standard economics and most traditional management theory (including product life cycle approaches), goods are homogeneous or tend to standardize. In evolutionary theory, conversely, products change, and often give way to families of products.

Following Saviotti, “The generation of variety is one of the fundamental trends in the development of economic systems, but one which has systematically been neglected in economics” [11: 93]. In SBIs, with their shortened life cycles of products, product variation is central in several industries, such as the computer and the semiconductor ones. These industries are “variation intensive”: their products tend not to stabilize, but to change extremely fast to serve new markets and applications.

3.5. Industry dynamics

Several competing explanations of industry dynamics can be found in the evolutionary and Schumpeterian literatures: the technological, the economic and the ecological.

Interpretations of such wide differences in industrial trajectories vary, even on the basis of common assumptions. Schumpeter’s insights can not easily accommodate such wide differences. In fact, for the older Schumpeter, innovation was linked with large enterprise and oligopoly [12]; industrial economics in the Schumpeterian tradition has followed the same line of reasoning and emphasized the study of the relationships between size and innovation, industrial concentration and R&D and related subjects [13].

3.6. Technological paradigms and technological regimes

The technological perspective argues that process and product innovation are the main dynamic factors explaining industry evolution. In a major plea for “technology-push” explanations, it was suggested that technology and R&D, particularly in SBIs, change economic structure [14]. This approach distinguishes between normal, continuous change that takes place along a given technological trajectory, and discontinuous change, that occurs when a major shift in the “outlook” (the concepts, the methods, and the perspective) takes place. This type of change is called paradigmatic. Health products research, for instance, experienced a paradigmatic change when it moved from traditional trial-and-error pharmacology to biotechnology in the 1970s and 1980s. Space launch technology is now facing a similar leap when moving from rockets (a technology that is based in Second World War concepts and evolving through a slow technological trajectory) to rocketplanes, combining rocket propulsion with aviation.

Technological regimes are also key elements in the explanation of industrial dynamics. Based on the work of Richard Nelson and others [15], industries have been classified into Schumpeterian Mark I and II. In the former, ease of entry, new firms and erosion of incumbent’s market position was predominant; in the latter, high barriers to entry, large firms and sustained dominance of market leaders are overwhelming [16,17].

3.7. Economic paradigms

A clear division exists between explanations of what drives changes emerging between “economic paradigms” and technological paradigms. Economic paradigm is based on the idiosyncratic relationship between users and producers. It tends to become routinized through time; semiconductor industries offer abundant evidence of distinctive dynamics (the American versus that of South East Asia) pulled by different types of users, private consumers in Japan, and the government in the United States [18: 45–6]. The evolution of technology is thus related to public policy and institutions. According to Andersen, new products sometimes require new, entrepreneurial firms and new users.

3.8. Organizational ecology

Organizational ecologists [19,20] studied the ecology of the entire industry. In organizational ecology, a few variables seem to explain at least part of the dynamics of the industry (measured by entry, exit, and number of firms). These explanatory variables include imitation, adaptation and selection. On the whole, however, and in spite of its many contributions, the ecology literature has emphasized inertia (organizations experience difficulties in changing) as a main characteristic of populations, and differential selection as the main mechanism of change.

3.9. Dominant designs and product life cycle

On the basis of the product life cycle, it has been argued that industries pass through a limited number of stages. At the beginning, entry is open and many firms compete to establish a dominant design. Once this design is achieved, the product standardizes and process technologies are developed to obtain economies of scale. At that phase, the number of entrants diminishes, exit increases, and the industry concentrates very fast. The competitive structure of the industry thus reflects the underlying product and process innovation [21].

4. A new typology

SBIs thus do not present similar dynamics over time. The evolution of concentration is one key element that may help to distinguish different dynamics, as it is strongly related to barriers to entry, R&D expenditures (challengers in contestable markets usually make a stronger investment in R&D to dislodge incumbents), appropriation regimes and the form of competition. In terms of industrial concentration thus, both at their inception and subsequent evolution, four different cases may be distinguished (Table 2).

The two Schumpeterian Mark I and II cases correspond to cells # 4 and 1 respectively. The typology in Table 2 shows that industries evolve through time, and that some of the early entrants may create high barriers to entry either through R&D or marketing or other processes.

This paper suggests that two polar situations should be added to the Mark I and II that the technological regimes literature has identified. I call them “dynamic

Table 2
Four stylized cases of industry evolution

		Initial conditions	
		Concentrated	Dispersed
PTrend	Concentration	(1) Chemicals, heavy electrical equipment, commercial aircraft, satellites, space launchers (Schumpeter Mark II)	(2) Software, pharmaceutical products (Kaldor–David–Arthur: dynamic increasing returns)
	Dispersion	(3) Semiconductor, computer and telecommunications equipment manufacturing (variation intensive industries)	(4) Biotechnology; professional equipment (Schumpeter Mark I)

increasing returns industries" (or Kaldor–David–Arthur industries) and "variation-intensive industries".

5. Explanatory model

The new typology of SBIs incorporates pre-existing evolutionary concepts and theoretical insights that help us develop at least two new major types. The trend towards dispersion is based on:

1. Sequential innovation: firms compete by launching new or improved products and creating new variations of existing products, some of them becoming new industries, together with synchronous competition using similar products.
2. Evolutionary branching: rapid innovation creates product variations that correspond to evolutionary branching in biology. Some product varieties prosper and create new variations, other disappear under the competition of new varieties. Rapid innovation and product variation blur continuously the frontiers of industries, making the work of the observer (both the statistician and the university) more difficult.
3. New technologies dividing older industries. Semiconductors changed the microelectronic industry (dominated by vacuum tubes), synthetic textiles overcame natural ones without replacing them, and biotechnology rejuvenated traditional pharmacology. New technologies represent watersheds, macro-mutations, or changes in the technological paradigms, revolutionizing entire industries.
4. Public institutions (public laboratories, universities, government subsidies, procurement) are overwhelming at the beginnings of SBIs. Their role seems to recede later, but again wide industrial and national differences subsist in the nurturing role of the state. They may support wide diverging industrial patterns of evolution.

Conversely, the trend towards concentration of originally Mark I industries is based on increasing returns. However, one must keep in mind the distinction between industries where increasing returns appeared from the start (such as the production of aircraft and rockets), and others where increasing returns developed later, with the maturing of the industry, such as pharmaceuticals, or software. Also, increasing returns may appear in the future in industries that are, today, dispersed, such as biotechnology or semiconductors. Future concentration may appear due either to new marketing conditions or to the fragmentation of the industry following the appearance of specific product variations (i.e. microprocessors as against DRAMs and other types of semiconductors).

Schumpeter Mark I and Mark II types do not adequately accommodate all possible SBIs, particularly when dynamic factors are included. After all, the fact that industry barriers and structures change through time is not a new discovery in industrial economics. In an evolutionary perspective, changing barriers and structures should be a major element for the understanding of industrial dynamics. I propose calling "dynamic increasing returns" industries those where barriers to entry increase through time and industrial concentration moves up due to large economies of scale and scope.

Also, business organization and government initiatives, which are so pervasive in SBIs, tend to create different dynamics in various industrial nations. While some SBIs tend to look alike across countries, and technological regimes are the main factors explaining their structure and evolution (particularly those in Schumpeter's Mark II industries), all the other types seem affected by the characteristics of their users (i.e. semiconductors) and the type of governmental preferences as to where R&D and development is to be performed. Biotechnology is probably the industry where the most striking differences appear from one country to another.

6. Historical evidence

Cell # 1 corresponds to Schumpeter Mark II industries that were born concentrated and remain concentrated. In both industries R&D and capital investment barriers to entry are high. These industries are characterized by a reduced number of users, inducing high industry stability. Examples of these SBIs are heavy electrical equipment industries, as well as the manufacturing of commercial aircraft, satellites and space launchers. For instance, most commercial aircraft is produced by half a dozen companies including Boeing (US), the European consortium Airbus (for large carriers), Canada's Bombardier, and Italy's Aeritalia (for regional jets). Boeing and Airbus are responsible for over 80% of the industry sales.

6.1. Case study 1: commercial aircraft

Commercial aircraft has been built in Europe and North America since the beginning of the twentieth century. The First World War brought some innovations from the military side to the new industry, but the first civilian successes were late to arrive: in the 1920s, Fokker in the Netherlands and de Havilland and A.V. Roe in the United Kingdom designed some most successful 10–20-seat aircraft in Europe. In the 1930s, Boeing and Douglas launched the modern airliner in the United States, with dominant designs such as the Boeing 247 (1933) and the Douglas DC-3 (1936). Between the wars, corporations based in France, Germany, Italy, and the Soviet Union joined the industry. Later Canada, Sweden, and Brazil started producing commercial aircraft. The Asian industrial countries were never able to produce commercial aircraft. Most producers were also manufacturers of defense jets and received strong support from their governments for military purposes.

By the late-1990s, the industry was strongly concentrated. The Soviet industry collapsed with the demise of communism, and today only produces a few jetliners for the local market. The merger of Boeing and McDonnell Douglas in 1997 created the largest manufacturer of civilian airliners (with close to 60% of the world's big aircraft with over 100 seats), followed by Airbus Industrie, the European consortium created in 1970, with nearly 40%. In the regional aircraft market (20 to 90 seat category), one company, Bombardier of Canada, has 60% of the global market. Economies of scale in R&D and manufacturing are used to explain such a high and stable level of concentration.

Cell # 2 is that of industries that started dispersed but have become concentrated, such as the manufacturing of pharmaceutical products, or are becoming concentrated, such as the software industry. These are the most obvious cases of dynamic increasing returns in the Kaldor–David–Arthur perspective. In both industries, R&D and marketing costs have increased enormously through time, while manufacturing costs are comparatively low. Also, users need some knowledge about the products to use them, and changing products requires investments. Therefore, once they have adopted a given product they tend to stick to it. Finally, worldwide marketing campaigns create world products. A few examples may illustrate these points.

The cost of developing a new drug has increased to attain US$230 million by the mid-1990s [22: 18]. R&D and marketing costs of new application software are also increasing very rapidly. By 1994, marketing costs, including advertising, already represented 30% of Microsoft revenues; R&D was the second major cost item, equaling 13% of the company's sales [23: 51]. In addition, marketing costs for new products are rapidly increasing: the marketing campaign for Windows 3.1 cost US$35 million,[1] that for Windows 95 attained US$200 million.[2] In both industries, winning products, such as Windows and Viagra, tend to diffuse rapidly over the globe and occupy a very large share of the world market, until a new superior product comes to dislodge them. In the software industry, WordStar (produced by MicroPro International) was the dominant word processor until it was replaced by WordPerfect (produced by Novell, then by Corel) in the late-1980s, which was to be displaced by Microsoft's Word in the 1990s [24].

The software industry exhibits another specific characteristic, which makes it

[1] See [38].
[2] See [39].

additionally prone to increasing returns, namely "network externalities": to increase the efficiency of the computer, users need to employ the same or at least compatible software. Thus, "dominant designs" tend to spread rapidly until they are replaced by new dominant designs. In the computer software industry, de facto standards have successively given pre-eminence to one product against others. The adoption of such standards tends to reduce the R&D and manufacturing costs per unit of software and drives direct competitors out of the market. The word processor example above shows the type of sequential competition associated with network externalities.

Similar sequential competition takes place in the pharmaceutical industry. Zantac (developed and manufactured by Glaxo) dislodged the first billion-dollar drug (the anti-ulcer Tagamet, produced by Smith Kline in the 1970s) in the 1980s. In this industry, as in software, companies compete through near substitutes [22: 116].

6.2. Case study 2: pharmaceuticals

This industry originated in the second half of the nineteenth century, with the development of the chemical industry, mainly in Eastern Europe, and the pathbreaking discoveries of L. Pasteur in France. As companies discovered the effects of the new dyes and other chemical compounds in "germs", new entrants arrived from the chemical industry in Germany, Switzerland, the United Kingdom, and the United States; others were manufacturers of machinery for the production of pills, tablets and capsules, such as Eli Lilly and W.E. Upjohn in the United States; finally physicians, having developed new products, such as W. Abbott in the United States, started their own firms [22]. These two latter types of entry were most frequent in the United States. The industry became more consolidated as R&D and marketing expenditures began to climb as a percentage of sales. By 1992, 20 large companies (12 of them based in the United States, three in Switzerland, two in Germany, two in the United Kingdom and one in France) concentrated close to 50% of global sales; in the late-1990s we witnessed a process of further concentration in the industry, with the merger of several of the largest firms, including Glaxo and Wellcome (based in the UK) to form the world leader, SmithKline and Beecham (based in the US and the UK respectively), and Sandoz and Ciba-Geigy (Switzerland) to create Novartis. Some observers forecast that by the turn of the century, the top ten manufacturers would be responsible for 80% of the pharmaceutical industry world's sales. The increasing costs of R&D, marketing and world patenting are cited as the main factors explaining concentration.

Industries included in Cell # 3 are increasingly dispersed. The semiconductor, computer and telecommunication equipment manufacturing industries show increasing economic and geographical dispersion, but this process did not happen as predicted by the PLC model; in the three cases dominant designs are giving way to a large family of products that represent evolutionary branching out of the original design. Also, evolutionary branching makes some sections of these industries evolve in different ways: within the semiconductor industry, the production of DRAMs (memory chips) is fairly dispersed, but that of microprocessors for the PC industry is almost totally concentrated in one firm, Intel, dominating almost 90% of the market (for semiconductors, see [25,26]; for computers [16,27,28]). The semiconductor industry has never witnessed the emergence of a dominant design. Fast innovation moves the product from one design to the next, and a family of designs evolves from the original transistor to present-day DRAMs, SRAMs, EPROMs, Flash, EEPROMs and other memory products, together with several types of microprocessors and other types of semiconductors [16]. Similarly, the computer industry presents at least ten different types or varieties of computers, ranging from mainframes to minicomputers, PCs, workstations, laptops and palmtops.

6.3. Case study 3: semiconductors

The industry started in 1948 with the invention of the transistor by Bell Laboratories, the central research center of AT&T. Government procurement and subsidies under defense agreements played a pivotal role in the development of the industry. In 1959, the first microcircuit was patented in the United States. It was followed by the first metal-oxide semiconductor (MOS), patented by RCA in 1962. In 1968 the complementary metal-oxide semiconductor (CMOS) was developed in Westinghouse, RCA and Sylvania. In 1971, Intel developed the microprocessor. A few years later dozens of companies in the United States were producing semiconductors, which were implanted in computers, telecommunications equipment, calculators, NCMs, robots, consumer electric appliances, watches, elevators, motor vehicles, aircraft and many other applications. The technology migrated to Western Europe, Japan, Canada, Korea, Taiwan, and other South-East Asian countries, and most recently China. Hundreds of companies produce an increasing variety of semiconductors for different applications. Computer as well as telecommunication equipment, aerospace and other electronic manufacturers are producing semiconductors, together with specialized producers. Korean companies dominate the market of DRAMs (memory chips) with nearly 25% of the market. Japanese and Taiwanese companies are also mostly active in this segment of the industry, pulled by consumer electronics demand. American companies dominate the higher end of the spectrum, including microprocessors for computers, with one company, Intel, representing close to 90% of the world production of these chips. Again, the US market has always been biased toward this type of semiconductors for the computer, military and aircraft, and telecommunication markets. The dynamics of this industry cannot be understood without considering these very different demand structures [29].

The computer industry presents a similar branching out of new designs from the original mainframe into mini- and microcomputers, supercomputers, personal computers (itself divided into portable computers, notebooks or pocket computers, and wearable computers), workstations, and network computers. All these products compete with each other and different dominant firms exist in each category. In variation-intensive industries, companies have developed different and diverging product and process technologies, and cater to different markets, thus reducing the opportunities for encompassing economies of scale, either in R&D, manufacturing or marketing.

6.4. Case study 4: professional and scientific equipment

This is, and has always been, a very fragmented industry, with thousands of firms producing thousands of different products. These include medical equipment (such as X-ray imaging tubes, scanning equipment using nuclear magnetic resonance, ultrasonic devices, and surgical laser equipment), scientific equipment (such as electron microscopes, particle accelerators, etc.) and professional and industrial equipment (lithographic instruments, graphic recorders, laser interferometers, metal and atomic emission detectors, etc.). Some of the companies having held a pioneer role in this industry for the past 50 years include Hewlett Packard, 3M, Honeywell, Thermo Electron, and Medtronic. Other important firms are Varian Associates, Perkin-Elmer, Beckman industries and US Surgical. It is to be noted that except for Hewlett Packard (which is a large multinational corporation) and 3M, most of the largest companies mentioned had revenues between one and two billion US dollars in 1997. Thousands of small- and medium-sized firms thrive on the production of a reduced number of instruments. These firms collect critical information from universities and government laboratories, where most of the inventions in this industry take place. Companies fill an important role, with their internal R&D facilities, in their developing, improving and diffusing the instruments around different industries and countries. ([30: Chapter 13]; [6: Chapter 2]; [31–33]).

Finally, cell # 4 represents industries that have started dispersed and remain dispersed, such as professional equipment and biotechnology (for the latter, see [34]). These SBIs are more like the original Schumpeter Mark I activities, with many innovative SMEs competing in a market characterized by low barriers to entry and high propensity to conduct R&D. This is not to say that economies of scale and scope may develop, creating a few large industry giants in the major niches. Today, however, and in the foreseeable future, these industries will remain fairly dispersed.

7. A comparison with other dynamic models

The proposed typology accommodates much of the existing evolutionary and non-evolutionary dynamic models. The new typology develops that proposed by Malerba and Orsenigo on the basis of previous work of Nelson and Winter. In my view, as in their approach, economic concentration is a key variable that makes the difference between types of industries. In this new typology, however, economic concentration explains patterns of innovation, but the *evolution* of economic concentration is also to be taken into account. Incorporating the dynamics of concentration change makes the typology more useful to explain changing patterns of innovation, and draws new bridges with evolutionary perspectives. In the previous Schumpeterian typology, patterns of innovation are technology-specific; in fact, they are technology-, economy- and nation-specific, as different technological regimes, user–producer relationships, and national systems of innovation shape both the level and the evolution of economic concentration, and through them, industrial dynamics.

The economic paradigm and user–producer dynamics that correspond the best to variation-intensive industries are cases where dominant designs fracture into families of products looking for—and interacting with—different users, as suggested by Andersen [18] and von Hippel [6]. The computer industry is a good case in point. The original users were government agencies, such as the defense and other government departments. The search for business users brought the minicomputer, while the personal, portable and booknote computers catered for individual consumers. Also, the stability of the concentrated industries in case 1 (heavy electrical equipment, defense products, and commercial aircraft) should be linked to the firmness of their markets (large electrical producers, defense establishments, and large airline corporations). Variation-intensive industries are those that are the closest to the product life cycle (PLC) model, but they differ crucially from the PLC model due to the successive appearance of new product variations in industries with rapid processes of creative destruction in dominant designs, and restricted economies of scale and scope among product varieties. In the professional instruments industry, product variety is also key, as is user–producer interaction.

Conversely, technological dynamics, i.e. technological trajectories, R&D economies of scale and appropriation regimes best explain the dynamics of other activities, such as the dynamic increasing returns group of industries. The pharmaceutical industry is a good example of this pattern. These are “technology push industries”, where powerful users are scanty and unable to shape either supply or demand.

8. Conclusion

Science-based industries differ widely in their industrial dynamics and patterns of technical change. Some of them are mature industries where technical change has slowed, like the manufacture of heavy electrical equipment and aircraft. Others are young industries enjoying rapid growth, where challengers endowed with new technological paradigms meet incumbents. This is the case with human drug industries, where dedicated biotechnology firms compete with large pharmaceutical corporations. Some SBIs are cases of technology push, where competition is made sequentially through product variation, while a few other industries boast dominant designs and stable technologies.

To accommodate such wide differences the proposed typology puts the emphasis on a key variable, namely the dynamics of industrial concentration, a dimension that is closely related to appropriation regimes, R&D intensity, barriers to entry and patterns of innovation. The typology is meant to replace through an incremental improvement, the Schumpeter Mark I and Mark II typology. It is also aimed at making better use of the new evolutionary concepts and creates a bridge between the different evolutionary currents on industrial dynamics, by showing that they may correspond to different industries.

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