Technological Regimes and Sources of Entrepreneurship

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ABSTRACT. This paper concerns the technological determinants of entrepreneurial behaviour. By applying a typology of technological regimes, which describes the nature of the technological environment in which firms operate, this paper examines the sources and obstacles to entrepreneurial entry related to the process of technical change. Two major points are suggested. First, innovation in technologies of high or increasing opportunities is not always associated with entrepreneurial behaviour, but can enhance the competitive advantage of existing firms. Second, opportunities for entrepreneurship are shaped by the *nature of knowledge* underlying different technologies. These points are illustrated using U.S. patent statistics classified by technical field and sector of firm's principal product activity. Different combinations of sources of technological entry barriers and technological opportunity are identified in science-based technologies, chemical technologies, core technologies in complex systems, product-engineering technologies and process-engineering technologies. This paper argues that such a characterisation of the dynamics of knowledge accumulation is important for interpreting the variety of dynamics of industrial competition.

1. Introduction

Following the neo-Schumpeterian tradition (Nelson and Winter, 1982) and the most recent contribution by Sutton (1998) to the theory of industrial organisation, this paper argues that technology is important in constraining the nature of market competition. Innovation allows new firms to enter the market and compete with varying degrees of success with established firms, but these opportunities for entrepreneurship and growth are structured by the nature of the technology that prevails in different sets of industrial activities.

This paper applies a typology of technological regimes, describing the technological environment in which firms operate, in order to illustrate the sources and obstacles to entrepreneurship related to the process of technical change. The basic idea is that technological regimes map the properties of innovative processes, the nature of knowledge bases, and the structure of the institutional set-up relevant to innovation, into different patterns of entrepreneurial behaviour.

This paper focuses on two questions concerning the relationship between technology and innovative entry. The first asks whether entrepreneurial firms show a greater capacity than established firms to acquire and develop technological competencies in fields of high or emerging technological opportunities. The second questions to what extent the relative ability of entrepreneurial firms and established firms to enter a certain technology is shaped by the nature of the underlying knowledge base. Using patent statistics, the paper addresses these questions by identifying a classification of technologies that, within the broad distinction of an "entrepreneurial" and a "routinised" regime, show distinct combinations of technological entry barriers and technological opportunity conditions.

The paper is organised as follows. In section 2 theoretical and empirical studies of the relationship between entrepreneurial entry and innovation are reviewed. Section 3 describes the main characteristics of a typology of technological regimes that characterise different sets of production activities. Section 4 carries out an empirical analysis of technological entry barriers and technological opportunity conditions in different fields of knowledge. In section 5 the typology of technological regimes is used to illustrate the possible

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sources of entrepreneurial behaviour in different industries. Section 6 presents the conclusions.

2. Innovation and industrial dynamics

In industrial economics, the interpretation of entry dynamics traditionally relies on the combination of profit opportunities determined by the level of market concentration and structural entry barriers originating in the existence of scale economies and other cost advantages of established firms with respect to potential entrants (Bain, 1956). Following this tradition, innovative activities in research and development (R&D) laboratories are regarded as entry barriers (Orr, 1974). Following Schumpeter's contribution, other authors more recently have stressed that innovation may represent a vehicle for new firms to successfully enter the market. Innovative entry is now widely regarded as a central force driving competition among firms (Dosi et al., 1997).

The link between industrial competition and technology has been illustrated by different approaches. Gort and Klepper (1982) argued that the demography of firms, including entries and exits, is shaped by the nature of technology associated with the various stages of the life cycle of a new product. In this interpretation, innovation is conducive to the entry of new firms at the early stages of the development of a new product, until a dominant design is established (Utterback and Suarez, 1993).

The idea that technology is important in constraining the pattern of industrial competition is also at the core of Sutton's "bounds" approach. Sutton (1998) argues that technologies that differ in their productivity of R&D activities and range of distinct technological trajectories that firms can explore imply different profit opportunities for a "potential" entrant to innovate and, therefore, different market configuration across industries.

In contrast with the product life cycle interpretation of entry, the neo-Schumpeterian approach emphasises that a high level of innovation activity is not necessarily conducive to entry. Rather, innovation may facilitate or hinder the entry of new firms depending on the nature of the technological environment characterising an industrial sector (Nelson and Winter, 1982). In contrast with interpretations of potential entry based on profit opportunities, Nelson and Winter stress the role played by technological opportunities to entry. These determine the possibility that innovative ideas relevant to a certain industry are generated by specific actors and then are commercially exploited by entry to the market, partly independent of direct profit considerations (Winter, 1984).

The concept of technological regime provides a description of the technological environment in which firms operate (Nelson and Winter, 1982). A technological regime defines the modal properties of learning processes, sources of knowledge and nature of knowledge bases that are associated with the innovation processes of firms active in distinct sets of production activities (Dosi, 1982). In the literature, two technological regimes are distinguished. An "entrepreneurial" regime facilitates innovative entry, while a "routinised" regime facilitates innovation by the incumbents in an industry (Winter, 1984). Such a distinction derives from the different traits of the innovative firm that are indicated by Schumpeter as being typical of different historical phases of economic development (1934, 1942). For this reason the two regimes are often labelled "Schumpeter Mark I" and "Schumpeter Mark II" (Dosi et al., 1995; Malerba and Orsenigo, 1996). Malerba and Orsenigo (1996), in particular, showed that Schumpeterian patterns of innovations are technology-specific.

Preliminary conjectures on the relationship between technological regimes and entry behaviour were advanced by Dosi and Lovallo (1997). They argued that (i) other things being equal, entry rates are higher the higher the perceived technological opportunities and (ii) knowledge serendipity (vs. specificity to a particular activity) positively influences entry rates.

Empirical studies that have addressed the relationship between the general level of innovative activity in an industry and entry dynamics have not produced entirely conclusive findings. Early studies in the field provided some empirical support for the assumption that a high intensity of R&D expenditure represented an entry barrier to an industry (Orr, 1974). However, empirical studies that included other technological characteristics of an industry among the explanatory variables, such as the innovativeness of small firms, did not find that the intensity of R&D

expenditure had a statistically significant effect on entry rate (Audretsch and Acs, 1994). In contrast, a positive, but rather weak, correlation has been observed between the rate of innovation and the rate of entry to an industry (Geroski, 1994), suggesting that innovation may foster entry. The low correlation between the intensity of innovative activities and entry rate reflects, to a certain extent, the different dynamics characterising innovation and entry. Rates of innovation tend to be highly industry-specific and persistent over time while rates of entry are more volatile, both over time and across industries (Geroski, 1994).

However, despite those purely random elements in the dynamics of firm entry, the empirical studies that included indicators of the presence of an "entrepreneurial" regime as opposed to a "routinised" regime (proxied by the innovation rate of small firms) in an industry showed that technological regimes are important in understanding the relationship between innovation and entry. Audretsch (1995) found evidence that technological environments that facilitate the innovative activity of new (generally small) firms promote the entry of new firms into an industry, while technological environments that facilitate innovation by established (large) firms represent an obstacle to the entry of new firms.

Furthermore, the empirical studies that have applied more direct measures of technological opportunity than the rate of innovation in an industry found systematic links between regimes and entries. Audretsch and Acs (1994) observed that the entry of new firms was helped by a relatively greater role of academic research in industrial innovation, while it was hindered by a strong scientific knowledge base in the process of firm innovation, which plausibly requires innovative activities to be carried out in large R&D laboratories, and by high degrees of uncertainty due to rapid changes in product specifications.

3. Characteristics of technological regimes

The empirical studies mentioned earlier suggest that entry dynamics differ in industries characterised by an "entrepreneurial" as opposed to a "routinised" technological regime. A further empirical problem that emanates from this characterisation of regimes is a cross-sectional one. It requires the establishment of which technological conditions favour an "entrepreneurial" pattern of innovation to emerge in some industries, and a "routinised" pattern in others (Winter, 1984). Taxonomic exercises of the characteristics of innovation processes in their sectoral differences contribute to the identification of those factors that in different technological environments favour or hamper innovative entrepreneurship.

Extending earlier work on taxonomic exercises of the organisational and structural traits of innovative firms (Pavitt, 1984) and innovation patterns in different technologies (Malerba and Orsenigo, 1996) a typology of regimes is applied that describes the properties of innovative processes in distinct groups of production activities. This typology provides a summary of the evidence on the sectoral diversity of technical change, which has become available in a wide range of empirical studies and data sources, and of new findings from the U.S. patent databases compiled at SPRU-Science and Technology Policy Research, University of Sussex.[1]

In Table I, the characteristics of regimes are illustrated in relation to a variety of dimensions: level of technological opportunity, technological entry barriers, cumulativeness of innovation, inter-firm diversity in the rate and directions of innovation, intensity and directions of diversification of the knowledge base, relevance of various external sources of knowledge, links with academic research, and nature of innovation (i.e. products and processes). The typology distinguishes the properties of innovative processes and knowledge bases in five regimes.

The *science-based* regime, in pharmaceuticals and electrical-electronics industries,[2] is characterised by a high level of technological opportunity, high technological entry barriers especially originating in the high industry-specificity of the knowledge base, and high cumulativeness of innovation. Firms are homogeneous in their rates and directions of innovation, which are focused on closely related technologies. Innovative activities are principally devoted to product innovation and benefit from the direct contribution of scientific advances in academic research.

The *fundamental-processes* regime, typified by the chemicals and petroleum industries, displays a medium level of technological opportunity, high

TABLE I
Technological regimes in the industrial system

	Technological opportunity	Technological entry barriers in knowledge and scale	Persistence of innovation	Inter firm diversity	Differentiation of the knowledge base (main directions)	External sources of knowledge	Links with academic research (fields of knowledge)	Nature of innovation
Science-based	High	High (knowledge)	High	Low	Low (horizontal and upstream, less often in pharmac.)	Public institutions and joint ventures	Strong and direct (mainly unpervasive fields of knowledge)	Product
Fundamental processes	Medium	High (scale)	High	Medium	Low (horizontal and upstream)	Affiliated firms and users	Quite important and direct (basic and applied science)	Process
Complex systems	Medium	Medium/High	High in technologies but not in products	Medium	High (upstream)	Complex system of sources	Quite important but indirect (engineering)	Product
Product engineering	Medium-high	Low	Medium-Low	High	High (horizontal and downstream)	Users	Not very important (pervasive mechanical engineering)	Product
Continuous processes	Low	Low	High in metallurgical technology but not in products (i.e. metals), and in build. materials	High	High (upstream)	Suppliers, esp. capital-embodied	Not very important (pervasive applied science, i.e. metallurgy and materials)	Process
			Low in the others		Low in food, drink (upstream and horizontal)		More important and direct in food (basic science)	

technological entry barriers especially related to scale advantages in innovation, and strong persistence of innovation. Innovation is mainly process innovation and, although affiliated firms and users represent the main external sources of knowledge, it benefits from the quite important and direct contribution of scientific advances in academic research.

The *complex (knowledge) system* regime, in aerospace and motor vehicles industries, is still characterised by medium-high levels of technological opportunity, entry barriers in knowledge and scale, and persistence of innovation. The distinctive feature of this regime is in the high degree of differentiation of technological competencies developed by firms, especially in upstream production technologies, and of external sources of knowledge, including an important, although indirect, contribution of academic research.

The *product-engineering* regime is characterised by a medium-high level of technological opportunity, low entry barriers to innovation and not very high persistence of innovation. This regime, which represents in particular non-electrical machinery and instruments,[3] is distinguished by the high diversity of technological trajectories explored by firms. Innovation in products benefits from external contributions of knowledge, mainly from users.

Lastly, the *continuous-processes* regime includes a variety of production activities such as metallurgical process industries – metals and building materials – chemical process industries – textiles and paper, food and tobacco. It is generally characterised by low technological opportunity, low technological entry barriers, and rather low persistence in innovation. Firms are technologically heterogeneous and their knowledge base is, on the whole, fairly differentiated among technical fields. Innovation in processes benefits from upstream sources of capital-embodied knowledge.

4. Opportunity of innovation and opportunity of entrepreneurship

A key concept in the characterisation of the regimes illustrated above is that of technological entry barriers, a concept that refers to the characteristics of the technologies upon which firms draw in developing new or improved products and production processes. In this section the concept of technological entry barrier is discussed in comparison with other interpretations, and statistical indicators are defined using the SPRU patent database.

In order to identify the sources of entry barriers into a technology, statistical measures of the specificity of knowledge to industrial applications and scale-related advantages in the generation of knowledge are related to a measure of the ability of new firms to acquire technological competencies in different fields. Furthermore, the relationship between technological opportunity conditions and technological entry barriers is explored. The purpose is to establish to what extent technologies of high opportunity of innovation and emerging technologies create opportunities for entrepreneurship.

The definition of technological entry barriers is based on the idea that the nature of the knowledge underlying a certain technology influences the extent to which new opportunities of innovation accrue to new firms as opposed to incumbents. The nature of knowledge varies across technologies in displaying different degrees of specificity, complexity, tacitness and cumulativeness (Winter, 1987; Malerba and Orsenigo, 1993).

The property of specificity reflects the fact that in some technologies, new knowledge can be applied to a variety of products and production processes, while in others it cannot. Winter (1984) argued that a knowledge base that is not specialised enhances the "potential" for innovative entry. The complexity of knowledge refers to the amount of information necessary to distinguish a certain item of knowledge from the possible alternatives and can be regarded as a source of entry barrier to a technical field. Cumulativeness reflects the fact that the probability of generating new knowledge in a certain field is enhanced by the technological competencies already acquired by a firm. The cumulative nature of knowledge may generate barriers to innovative entry related to the scale of production. This occurs as incumbent firms, by exploiting opportunities of innovation stemming from their normal activities of research and production, grow bigger and at the same time, because of the cumulativeness of learning, more innovative (Dosi et al., 1995).

With regard to the attribute of specificity, a distinction has to be made between technologies that are pervasive in *production processes* and technologies that are pervasive in *products*. The former are technologies that are applied widely in different production processes across the broad range of industries and are likely to facilitate entry via spin-offs of employees from established firms (Rosenberg, 1976; Patel and Pavitt, 1994). The latter are technologies that enable only specific industries to generating a continuous stream of new products. This property of knowledge can be better described as "technological richness",[4] and is typical of technologies that are direct applications of scientific findings because of the "generic" nature of scientific knowledge. Under these conditions opportunities are likely to be generated for both innovative entrepreneurship, especially via spin-offs from academic research, and incumbents' growth.

The interpretation of entry barriers into a technology based on the nature of knowledge contrasts with interpretations based on the costs of production of a technology. The high costs of production of a technology increase the advantage of larger scale producers and, therefore, increase the barriers to entry into the field (Freeman and Soete, 1997). High costs of production of a technology arise from the requirements of in-house technical competencies and complementary assets in the innovation process (Teece, 1986) and from scale requirements in the innovation process. There are various factors that are considered to work to the advantage of large firms in innovation, such as static scale economies in R&D activities (e.g. high fixed costs), dynamic scale economies along learning curves, ease of access to internal funding for risky research projects with imperfect capital markets, etc. However, although many empirical studies have focused on the relationship between innovation and the size of the firm, often in the form of the 'Schumpeterian hypotheses', firm size does do not appear to be among the main explanatory factors of innovation (Cohen, 1995).

In general, the properties describing the nature of knowledge are difficult to measure. In order to express the nature of the knowledge base in different industries, Cohen and Levinthal (1990), for example, opted to study the importance of different fields of knowledge – each embodying certain (unmeasured) characteristics – in innovative processes. Following this approach, it can be expected that the innovative behaviour of new firms as opposed to established firms, varies in technologies that rely on different broad areas of knowledge. In principle, four generic knowledge bases can be distinguished: electrical-electronics, chemicals, mechanical machinery, and software.

The SPRU patent databases consist of the U.S. patents granted to the set of the world's 500 largest firms, in the period 1981–1990, classified by 34 technical fields and 16 sectors of firms' principal product activity. Furthermore, in each technical field the distribution of the U.S. patents granted to the set of the 500 largest firms in the same period, to other firms (including public institutions) and to private individuals, is known.

With regard to the discussion of differences across technologies there are some limitations to the use of patent statistics as a measure of technological activity, that have to be considered (Patel and Pavitt, 1995). First, the propensity to patent the results of innovative activities differs between technologies. Because of this, Patel and Pavitt (1995) suggest that the normalised values by sectoral totals in patenting are most reliable. Second, patents measure codified knowledge, while a high proportion of firm technological capabilities is non-codified (tacit) and the degree of tacitness may vary across technologies (Winter, 1987). However, it has been argued that these two forms of knowledge are complementary rather than being substitutes for one another (Patel and Pavitt, 1997). Third, a limitation of patent statistics, but also of other indicators such as R&D, is that they do not capture satisfactorily advances in software technology. The analysis thus focuses on technologies with a generic knowledge base in electrical-electronics, chemicals, and mechanical machinery.

For the purpose of this analysis, an important advantage of patent statistics is that they allow a classification of technological activities according to the nature of the acquired competencies (represented by the classification of patents in different technical fields) and to the nature of the production activities in which such competencies are applied for product and process innovations (represented by the classification of patenting firms by sector of principal product activity).

By using the joint distribution of patents of the world's largest firms by technical field and by sector of principal product activity, it is possible to construct a measure of the specificity of knowledge to industrial applications. In each technical field the Herfindhal index of concentration of patents across the 16 sectors of principal product activity of the world's largest firms is calculated.[5] A high value of the Herfindhal index reveals that knowledge generated in a technology is specific to some industrial applications and not others. Because of the broad classification of industrial sectors in the database, the Herfindhal index captures the specificity of knowledge more in production processes than in products. The latter would require a detailed classification of products within an industry.

The extent to which the nature of knowledge leads to scale-related advantages in the generation of technological competencies is expressed by the percentage of patents in a technical field granted to the set of the world's largest firms. As previously discussed, this measure reflects both the costs of production of a technology and the degree of cumulativeness of knowledge, the latter being independent of the existence of scale economies.

Among the various sources of patenting in a technical field, the majority of private individuals are represented by individual owners of very small firms. Therefore, the share of patents granted to private individuals is used as a proxy of the ability of new (generally, very small) firms to exploit technological opportunities in a field of knowledge.

Finally, the share of the total patents granted in a specific technical field, in the period 1981–1994, is used as a measure of the general level of technological opportunity associated with a field of knowledge. This reflects the "ease" to innovate in a technology, independent of which agents are able to exploit such opportunities. Furthermore, the rate of growth in the number of patents in 1981–1994 with respect to the period 1969–1980 describes the long-term variations of opportunity conditions in the various technologies.

In Table II the correlation coefficients between the various technological dimensions previously defined are reported for the 34 technical fields.

In Table II, the patent share of private individual firms is statistically and negatively correlated to the Herfindhal index of concentration of patents across industrial applications and to the patent share of large firms.[6] Large firms have a higher share of technological activity in fields of knowledge that are specific to industrial applications, while private individual firms have a higher share of technological activity in fields of knowledge that are pervasive across industrial applications. The specificity of knowledge and scale-related advantages in the generation of knowledge represent sources of technological entry barrier.

The coefficients in Table II also show that the level of technological opportunity and its rate of change over time are not significantly correlated to the level of technological entry barriers. In particular, the patent shares of large firms and that of private individuals are not statistically corre-

TABLE II
Technological entry barriers and technological opportunity: correlation matrix in 34 technical fields (p-value in parentheses)

	Herfindhal	Share large firms	Share individuals	Patent share	Patent growth
Herfindhal	1	0.61 (0.000)	–0.48 (0.004)	–0.41 (0.015)	0.14 (0.451)
Share large firms		1	–0.92 (0.000)	–0.21 (0.233)	0.16 (0.363)
Share individuals			1	0.14 (0.451)	–0.13 (0.456)
Patent share				1	0.13 (0.450)
Patent growth					1

Source: Author's calculation from the SPRU patent databases.

lated with the total patent share and the patent growth rate in a field. In general new firms do not appear to have an innovative advantage in fields of high or increasing opportunities (indeed, though not statistically significant, the correlation coefficient of the patent growth rate with the patent share of large firms is slightly positive). A negative and statistically significant correlation is observable between the total patent share in a field and the Herfindhal index of concentration of patents in that field across production activities. Thus, more pervasive technologies tend to present higher levels of opportunity for innovation. However, these are not fast growing technologies as the correlation between the Herfindhal index and the patent growth rate is not statistically significant (indeed the coefficient has a positive sign).

In summary, the empirical evidence suggests that technological opportunity conditions and technological entry barriers define two independent dimensions of the dynamics of knowledge accumulation. Fields of high or increasing opportunity are not necessarily associated with an innovative advantage of new firms, but may well enhance the innovative advantage of established firms. The extent to which technology creates opportunities for entrepreneurship – as opposed to strengthening opportunities for incumbents' growth – depends on the nature of the underlying knowledge.

4.1. *Scale- and knowledge-related sources of technological entry barriers*

It was previously argued that technologies that share a similar generic knowledge base (i.e. electrical-electronics, non-electrical machinery and chemicals) are likely to display similar conditions of technological entry barrier. For this purpose a more detailed analysis is carried out in order to identify sets of technologies with similar patterns of entry barrier. The analysis also illustrates the characteristics of entry barriers in those technologies that compose the knowledge base of industries in different technological regimes (Table I).

Because of the significant correlation among the various components of technological entry barriers previously defined, they can be summarised into a unique factor by a principal component analysis. This factor explains about 79% of the total variability and presents correlation coefficients of 0.76 with the Herfindhal index of concentration, of 0.97 with the patent share of large firms and of –0.92 with the patent share of private individuals. On the basis of this factor, a general ranking of technologies according to decreasing strengths of entry barriers is established (Table III).

Because the remaining proportion of variability is due to the relative importance that the specificity of knowledge as opposed to scale-related factors plays in creating entry barriers to innovation for a given general level, the original variables are also reported and the differences in the rankings of technologies according to these two components are calculated (Table III). This distinction appears to be important as the various sources of technological entry barriers may have a different impact on the different types of industrial entry. Either a new firm, or an established firm diversifying its profile, may be involved. A possible conjecture is that the specificity of knowledge to industrial applications may represent a major obstacle to diversification by established firms, while those barriers related to scale advantages in learning processes are more likely to obstruct the entry of new firms.

Table III suggests that distinct groups of technologies characterised by different generic knowledge bases do show different conditions of "accessibility" for new firms as opposed to established firms. All the electronic technologies display high barriers to innovative entry, while these are relatively lower for electrical technologies (electrical devices and systems, general electrical industrial apparatus), although still at a fairly high level. High technological entry barriers are also present in chemical technologies, with the exclusion of chemical processes. Within this group a distinction can be drawn between organic and inorganic chemicals, which display relatively higher scale-advantages than knowledge specificity, and drugs and bioengineering, in which conditions are the reverse.

A medium level of technological entry barriers characterises a set of *process* engineering technologies related to firms' production processes. It includes metallurgical processes, materials and chemical processes. These technologies are highly pervasive across the industrial system but involve

TABLE III
Barriers to innovative entry in 34 technical fields: 1981–1990

	Technical field	Factor (1)	Herfindhal (2)	Share large firms (3)	Share individuals (4)	Rank diff. (2)–(3)
High	Semiconductors	1.43	0.54	78.0	3.1	4
	Agricultural chemicals	1.41	0.61	72.3	4.1	–3
	Photography and photocopy	1.37	0.53	78.6	5.0	7
	Hydrocarbons, mineral oils etc.	1.31	0.55	74.6	5.1	2
	Nuclear reactions: systems and elements	1.21	0.72	55.8	5.3	–14
	Organic chemicals	0.99	0.33	74.2	2.4	11
	Bleaching dyeing and disinfecting	0.87	0.52	60.6	7.9	–1
	Road vehicles and engines	0.81	0.57	64.9	16.4	–4
	Telecommunications	0.80	0.54	57.5	9.4	–6
	Image and sound equipment	0.72	0.45	62.6	10.3	3
	Calculators, computers, etc.	0.72	0.32	67.1	5.9	10
	Drugs and bioengineering	0.45	0.39	51.9	7.9	–7
	Inorganic chemicals	0.44	0.24	61.1	5.9	11
	Electrical devices and systems	0.41	0.48	51.8	14.8	–10
Medium	Metallurgical and metal treatment processes	0.20	0.19	56.8	8.1	10
	Aircraft	0.18	0.57	45.9	23.9	–19
	Mining and wells machinery and proc.	0.11	0.34	52.8	17.3	–2
	Materials (inc. glass and ceramics)	0.10	0.14	57.9	8.7	17
	General electrical industrial apparatus	0.00	0.28	47.8	14.0	–4
	Chemical processes	–0.01	0.16	52.5	10.3	9
	Power plants	–0.02	0.23	58.5	19.5	10
	Plastic and rubber products	–0.12	0.15	51.9	12.8	10
	Food and tobacco (processes and products)	–0.21	0.25	43.3	15.7	–5
	Instruments and controls	–0.22	0.21	47.2	16.5	0
Low	General non-electrical industrial equip.	–0.65	0.17	39.5	23.2	0
	Apparatus for chemicals, food, glass etc.	–0.84	0.13	36.2	24.5	4
	Metallurgical and metalworking equip.	–0.85	0.16	32.9	24.3	0
	Assembling and material handling apparatus	–0.99	0.12	29.0	23.5	4
	Other transport equipment (exc. aircraft)	–1.17	0.35	24.7	41.5	–16
	Non-electrical specialised machinery	–1.23	0.11	24.1	28.0	3
	Dentistry and surgery	–1.49	0.20	19.3	39.0	–9
	Miscellaneous metal products	–1.55	0.12	21.5	37.4	0
	Textile, clothing, leather, wood products	–1.97	0.26	10.6	52.4	–16
	Other – (Ammunitions and weapons, etc.)	–2.21	0.11	12.5	52.6	1
Total		–	0.14	46.1	19.0	–

Source: Author's calculation from the SPRU databases of the world's largest firms and U.S. patents granted.

some sort of scale advantage in the learning processes.

In contrast, a low level of technological entry barrier, both in knowledge and scale, distinguishes a set of *product* engineering technologies related to firm production processes. This set includes technologies in non-electrical machinery and instrumentation. Particularly low technological entry barriers are observed in other transportation, medical technology, miscellaneous metal products, textiles, and other manufacturing, while they are relatively higher in plastic and rubber products, food and tobacco.

Transport technologies present a rather differentiated behaviour that requires consideration of the data source. While technological entry barriers are, as might be expected, fairly high in motor vehicles and engines, they are, rather unexpectedly, at a medium level in aircraft technology. A first possible explanation of this finding resides in the low propensity to patent in aircraft technology. This trend may produce misleading results.

Nevertheless, the high level of the Herfindhal index of concentration captures the strong specificity of knowledge in this field. Indeed, with respect to the knowledge specificity dimension only, from all fields motor vehicle and engine technology and aircraft technology rank third after nuclear reaction technology and agricultural chemicals.

In aircraft technology, the low level in the summary indicator of technological entry barriers seems to reflect a particular distribution of patents. Such a distribution displays a rather low patent share of large firms, about 46%, and a surprisingly high patent share of private individuals, about 24%. The remaining high share of patents (more than 30%) however, includes both patents by small-medium firms and patents by government agencies. As the data used do not distinguish between these two components, there may be an element of bias in the assessment of the innovative advantage of large versus small-medium firms, especially as, in the case of the aircraft technology, the patent activity of government agencies is particularly high (Patel and Pavitt, 1991).

4.2. *Technological opportunity conditions*

The level of technological opportunity and its long-term rate of change capture two different aspects of the dynamics of knowledge accumulation (in Table II the total patent share and the patent growth rate across technical fields were not significantly correlated with one another). The former reflects the ease with which opportunities for innovation are generated in a certain technology; the latter reflects the occurrence of long-term paradigm-shifts in the dynamics of knowledge. In order to characterise patterns of technological opportunity in distinct sets of technologies these two variables are reported in Table IV.

Electronic technologies are generally characterised by high and increasing levels of technological opportunity, especially in computers, imaging and sound equipment, and telecommunication equipment. In this group, the technologies of photography and photocopying and of semiconductors have patent shares that are below the average, but which have nevertheless significantly increased over time. Electrical technologies present high levels of technological opportunity that have only moderately increased over time.

Technologies within the chemical area present differentiated conditions of technological opportunity. At one extreme, a first group of technologies – organic chemicals, drugs and bioengineering – has a high level of technological opportunity, which has rapidly increased in pharmaceuticals while it has declined in organic chemicals. At the other extreme, a second group of technologies – hydrocarbons, agricultural chemicals, inorganic chemicals, bleaching etc. – is characterised by fairly low levels of opportunity for innovation. Within this group, the level of opportunity has noticeably increased in agricultural chemicals, while it has significantly declined in all the other technologies.

Among the technologies related to production processes, mechanical engineering technologies have fairly high levels of technological opportunity. However, the level for non-electrical machinery has shown a significant decline over time while in instruments it has increased. In the remaining set of technologies related to production processes – chemical processes, materials and metallurgical processes – technological opportunities have generally increased, although less rapidly in metallurgical technology where the level is fairly low.

Transport technologies present a rather low level of opportunity for innovation. This has noticeably increased in motor vehicles and engines, while it has declined in aircraft technology. Of the remaining technologies, the level of technological opportunity is low in rubber and plastics, food and tobacco, textiles and wood products. Distinctive traits characterise medical technology which shows a fairly high level of opportunity rapidly increasing over time (at a rate second only to drugs and bioengineering).

4.3. *A classification of technologies*

In summarising the patterns of technological opportunity and technological entry barriers examined above, distinct properties of the dynamics of knowledge accumulation can be identified in different sets of technologies. In electrical/electronic technologies conditions of high opportunity prevail along with high entry

TABLE IV
Opportunity of innovation in 34 technical fields: 1981–1994

Technical field	Share of patents	Growth rate of patents
Instruments and controls	8.3	21.6
Organic chemicals	6.8	–17.2
Chemical processes	5.6	24.3
Non-electrical specialised machinery	5.6	–11.9
Other – (Ammunitions and weapons, etc.)	5.5	12.3
General non-electrical industrial equipment	5.4	–0.3
Calculators, computers, etc.	5.1	99.0
Miscellaneous metal products	4.9	11.1
Drugs and bioengineering	4.7	126.1
Image and sound equipment	4.4	82.4
Telecommunications	4.2	21.0
Metallurgical and metalworking equipment	3.9	–6.8
General electrical industrial apparatus	3.7	10.6
Dentistry and surgery	3.5	123.9
Electrical devices and systems	3.3	22.1
Apparatus for chemicals, food, glass etc.	3.2	–3.9
Materials (inc. glass and ceramics)	2.9	59.1
Photography and photocopy	2.5	37.4
Assembling and material handling apparatus	2.3	–11.5
Other transport equipment (exc. aircraft)	2.2	4.0
Semiconductors	1.8	85.4
Road vehicles and engines	1.8	50.2
Textile, clothing, leather, wood products	1.1	26.1
Metallurgical and metal treatment processes	1.0	8.2
Plastic and rubber products	1.0	18.8
Mining and wells machinery and processes	1.0	14.7
Food and tobacco (processes and products)	0.9	4.6
Hydrocarbons, mineral oils, etc.	0.9	–4.1
Inorganic chemicals	0.7	–12.3
Power plants	0.6	–3.3
Agricultural chemicals	0.4	43.5
Aircraft	0.3	–1.6
Induced nuclear reactions: systems and elements	0.3	40.9
Bleaching, dyeing and disinfecting	0.3	–19.6
Total	100	18.2

Source: Author's calculation from the SPRU database of U.S. patents granted.

barriers. Pharmaceutical technologies display high technological opportunity and high entry barriers, especially for lateral entry. In contrast, chemical technologies are characterised by low opportunity and high entry barriers especially to green-field entry. Technologies related to complex systems, such as transportation and nuclear technologies, display fairly low opportunity and high entry barriers.

Product engineering technologies that are related to firms' production processes – non-electrical machinery and instrumentation – and medical technology are characterised by the coexistence of fairly high levels of opportunity and low entry barriers.[7]

Process engineering technologies that are related to firms' production processes – chemical processes, metallurgical processes and materials – display medium barriers to green-field entry and low barriers to lateral entry. In this group the level of technological opportunity is rather varied being high in chemical processes and low in metallurgical processes. The remaining technologies – food and tobacco, plastic and rubber products, textiles and wood products, and other transportation – show low opportunity and low entry barriers.

While the above description represents the "status" of technologies, which can assumed to be relatively invariant over time at least with respect to fast-changing variables of firms' competition, long-term changes, orthogonal to such "status", are highlighted by the data. These show a long-term shift from a mechanical paradigm to an electronic paradigm, also associated with a considerable increase of innovative activity in motor vehicle and engine technology. In chemical technologies a long-term shift occurred from a chemistry-based paradigm to a biology-based paradigm, which involved technologies at both extremes of technological opportunity levels. The level of innovative activity has also considerably increased in medical technology and materials.

5. Technological regimes and entrepreneurship

The nature of knowledge represents one of the factors that contribute to creating opportunities for "potential" innovative entry into an industry. This is also determined by how these opportunities interact with the institutional set-up and the structure of the production system in which firms' activities take place. In this respect, Winter (1987) argued that even when the industry's activity involves specialised knowledge, innovative ideas might still accrue to potential entrants when such knowledge is accessible to a large number of individuals in contact with the industry.

According to Winter (1987), different individuals are exposed to the same knowledge base relevant for innovation in a specific industry through a variety of activities. These consist of research and production activities carried out by public institutions, competitors, and firms in horizontally related industries, users in downstream industries and suppliers of capital-embodied knowledge. Entry into the market may take place through different modes. Green-field entries may occur through spin-offs of employees from existing firms active in the same or related industries or of researchers in public institutions. Lateral entries of existing firms may originate in horizontally and vertically related industries. The external sources of knowledge prevailing in a specific regime are thus important for entrepreneurship as they structure the channels and modes of innovative entry into an industry. Typically, innovative entry via spin-offs from upstream industries is likely in the product-engineering regime, in which users represent distinctive external sources of knowledge (Table I).

While the factors mentioned above influence the cognitive abilities of "potential" entrants to acquire technological competencies in certain fields of knowledge, the "actual" decision about entry is constrained by the complexity of the knowledge base that is required to develop and commercialise new or improved products and production processes (Winter, 1984; Pavitt, 1998; Malerba and Orsenigo, 1993). Therefore, in defining the conditions leading to innovative entry in an industry a distinction needs to be made between the technology dimension and the product dimension of innovative processes. Innovation in products and production processes may require firms to manage and co-ordinate a broad array of different sources of knowledge, internal and external to the firm, and to integrate different scientific disciplines and technologies. Such conditions reflect the complexity of products and/or of production processes and represent an obstacle to innovative entry into a sector.

This is especially the case in the transportation industries typical of a complex system regime (Table I). In these industries, suppliers represent important sources of external knowledge and therefore potential sources of innovative entry. However, such a contribution has to be integrated within a complex system of external sources, in which other actors, such as public institutions, users, and competitors, are of considerable relevance, and with a highly differentiated profile of in-house competencies that are developed by producers not only in transportation technologies but also in the mechanical and electrical-electronic area. Therefore, although suppliers from the product-engineering regime do acquire competencies in transportation technologies, they are not likely to enter the transportation sector.

Another dimension of technological regimes that may enhance or hamper opportunities for entrepreneurship is the degree of technological diversity between firms within an industry. In the neo-Schumpeterian literature it has been argued that the nature of technology in a specific regime constrains the set of distinct technological trajectories that firms can explore and the menu of innovative strategies available to firms (Dosi, 1982, 1988; Malerba and Orsenigo, 1993). Innovative entry may then be favoured in an industry in which the prevailing technological regime entails a variety of possible search trajectories and innovative behaviours (for example firms with a different intensity of R&D expenditure may coexist in the market).

A similar argument based on consideration of the profit opportunities of entry is made by Sutton (1998). Sutton argues that the co-existence of diverse technological trajectories, associated with differentiated products in an industry, increases the profitability of potential innovative entry and thus reduces market concentration. Sutton's argument was applied in particular to explain the low levels of market concentration observed in fairly high-tech industries, such as non-electrical machinery and instrumentation. As illustrated in Table I, in these industries, typical of a product-engineering regime, firms undertake fairly intense technological activities, with similar rates of innovation, along distinct technological trajectories.

A variety of factors seem thus to intervene in the way innovation influences entry. Some of these are related to the nature of knowledge that underlies technologies, a dimension that has been identified as "technological entry barriers". Others are related to the properties of innovation activities in products or production processes and to the institutional set up contributing to the innovation processes. Given this variety of factors, technological regimes provide an analytical framework for the interpretation of different pattern of entrepreneurial entry, both in terms of entry rates and types of entry (i.e. green-field entry vs. lateral entry). The typology of regimes represented in Table I can be used to identify the prevalent conditions that in different technological environments create or obstruct opportunities for entrepreneurial behaviour. These are summarised in Table V.

6. Conclusions

Innovation is an important driving force behind the dynamic of firms' competition in an industry. In the process of Schumpeterian competition two mechanisms operate. In one, new firms enter the market by realising innovative ideas. In the other, established firms introduce new solutions as a result of cumulative processes of learning associated with their specific production and research activities. These two mechanisms are not mutually exclusive, and the balance between the two that prevails in an industry is shaped to a large extent by the nature of the technological knowledge upon which innovative activities rely.

This paper has explored the technological determinants of entrepreneurial behaviour. By applying a taxonomy of technological regimes, it showed that the technological environment in which firms are active constrains opportunities for entrepreneurial entry. Using patent data the paper pointed out that new technologies do not always create opportunities for entrepreneurs and explored how

TABLE V
Sources and obstacles to entrepreneurship across technological regimes

Technological regime	Obstacles	Sources
Science-based	• Specificity of knowledge • Cumulativeness of learning	• Technological richness of knowledge
Fundamental processes	• Scale • Cumulativeness of learning	
Complex systems	• Complexity of the internal and external knowledge bases	
Product engineering		• Pervasiveness of knowledge • Diversity of trajectories • Users source of knowledge
Continuous processes		• Diversity of innovation strategies • Embodied knowledge

the nature of knowledge influences these opportunities. By doing so, the paper showed that technology contributes to shape the nature of industrial competition and that looking at technology differences is important to account for diverse patterns of industrial dynamics.

This paper has attempted to move beyond the distinction of stylised "entrepreneurial" and "routinised" regimes, in particular stressing the relationship between such patterns and the nature of the knowledge bases. The results of the empirical analysis confirmed earlier findings that the innovative advantage of new firms as opposed to established firms varies significantly across technological classes (Malerba and Orsenigo, 1996).

The main purpose of this paper has been to illustrate the variety of factors that contribute to shaping the relationship between technical change and entrepreneurial behaviour. In this respect this work represents only a first step in the exploration of patterns of industrial competition driven by technical change. Further research and econometric analysis would be required to test the properties of entry dynamics in different technological regimes.

Notes

[1] A detailed account of the construction of the taxonomy is in Marsili (2001).
[2] This group also comprises the photography and photocopy industry, which in the standard industrial classification falls within the instruments sector.
[3] As part of the instruments sector, the product-engineering regime includes machine controls, and electrical and mechanical instruments, while it excludes the photography and photocopy industry. Fabricated metal products and rubber and plastic products are also classified under this regime.
[4] Pavitt personal conversation.
[5] The (inverse of) Herfindhal index represents a measure of diversity. The value declines as the number of sectors of application of the new knowledge increases and as the disparity of the shares of technological activity in different industrial applications decreases. The Herfindhal index is used, for example, by Patel and Pavitt (1994). Some authors prefer to use the Entropy coefficient borrowed from information theory. Because in this paper the Herfindhal index is used with the goal mainly of studying technology ranking, it is assumed that differences among indicators have no major implications for such ranking.
[6] The shares of other firms (including public institutions) display a pattern similar to that for private individuals. This variable is significantly correlated with positive coefficient to the share of patents of private individuals, with negative coefficient to the share of patents of large firms and to the Herfindhal index. It is not significantly correlated to the total patent share and to the patent growth rate.
[7] Medical technology represents a "distinctive" or "core" competence of firms active in the pharmaceuticals industry.

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