# *Technological Regimes and Sectoral Patterns of Innovative Activities*

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*This paper focuses on the relationships between observed patterns of innovative activities within a sector and the related context and underlying microeconomic processes that might account for them. It claims that there are some invariant features (with respect to relative prices and incentives mechanisms) of learning and knowledge accumulation that greatly affect the rate and structure of innovative activity. These features are different across sectors. The paper proposes that the specific pattern of innovative activity of a sector can be explained as the outcome of different technological regimes that are implied by the nature of technology and knowledge. The notion of technological regime provides a synthetic representation of some of the most important economic properties of technologies and of the characteristics of the learning processes that are involved in innovative activities.*

## 1. *Introduction*

The ways in which innovative activities take place in industries and technologies may be quite different. One may find that in certain technologies innovative activities are concentrated among few major innovators, while in others innovative activities are distributed among larger numbers of firms. In certain technologies large firms do the bulk of innovative activities, while in others small firms are quite active. In some technologies new innovators may enter a sector more or less at the same time and then either grow or disappear with time. As a consequence, the ranking of the major innovators may remain stable over long periods of time or change significantly in a very short time. In general, turbulence in innovative activities appears to be a fundamental feature of industrial evolution. However, industrial evolution appears to be characterized also by remarkable degrees of persistence in the innovative activities of a large number of firms within an industry. Finally, large and





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significant intersectoral differences in the degrees of technological entry and exit, turbulence and stability, variety and persistence are noticed.

This paper tries to address these issues by focusing on the relationships between the observed patterns of innovative activities within a sector and the related context and underlying microeconomic processes that might account for them. Specifically, the paper surveys some results of empirical and theoretical analyses, suggesting that the notion of *technological regimes* may be a fruitful concept for studying the different ways in which innovative activities are organized and industries evolve over time.

This difference in the structure of innovative activities may be related to a fundamental distinction between Schumpeter Mark I and Schumpeter Mark II technologies. Schumpeter identified two major patterns of innovative activities. *Schumpeter Mark I* is characterized by 'creative distruction' with technological ease of entry and a major role played by entrepreneurs and new firms in innovative activities. *Schumpeter Mark II* is characterized by 'creative accumulation' with the prevalence of large established firms and the presence of relevant barriers to entry for new innovators.

During the last forty years this characterization of innovative activities by Schumpeter has encouraged different scholarly traditions aiming at the empirical verification of the two patterns. The first, and oldest, tradition was mainly centred on the firm. It attempted to assess the role of firm size and of monopoly power in innovation (Kamien and Schwartz, 1982). A second tradition focused on the relationship between market structure and the rate of innovation. The inconclusive results obtained in these empirical analyses are due to the neglected role of opportunity and appropriability conditions in the various industries (Levin *et al.*, 1985) and of the endogenous relationship between firm size, concentration and technological change (Nelson and Winter, 1982).

While fully recognizing the dynamic endogenous relationship between firm size, market structure and innovation, this paper focuses on the relationship between the technological and knowledge environment and the rate of innovation and the structure of innovative activities within sectors. The basic claim is that there are some rather invariant features (with respect to relative prices and incentives mechanisms) of learning and knowledge accumulation that greatly affect the rate and structure of innovative activity. These features are different across sectors. In sum, this paper proposes that the specific pattern of innovative activity of a sector can be explained as the outcome of different *technological regimes* that are implied by the nature of technology and knowledge. The notion of technological regime provides a synthetic representation of some of the most important economic properties of technologies and of the characteristics of the learning processes that are involved in innovative activities.

The paper is organized as follows. The first part reports some empirical results on the patterns of innovative activities. It shows that the patterns of innovative activities have major differences across technologies, but remarkable similarities across countries in the same technology. Against this background, it is suggested that one can meaningfully identify two basic groups of technologies, in which innovation proceeds in quite distinct ways. One group resembles the Schumpeter Mark I (or creative destruction) model. The second group is more akin to the Schumpeter Mark II (creative accumulation) model (section 2). The second part of the paper introduces the concept of 'technological regimes', defined in terms of opportunity, appropriability, cumulativeness and knowledge base conditions, and analyses the relationship between technological regimes and the specific pattern of innovative activity in a sector (section 3). In section 4 specific aspects such as technological entry and exit, spatial dimensions of patterns of innovative activities and sectoral systems of innovation are discussed in more detail. Section 5 provides some final conclusions.

## 2. *Sectoral Patterns of Innovative Activities: The Empirical Evidence*

### 2.1 Schumpeter Mark I and Schumpeter Mark II

Differences in the structure of innovative activities may be related to a fundamental distinction between Schumpeter Mark I and Schumpeter Mark II technologies. Schumpeter identified two major patterns of innovative activities. The first one, subsequently labelled[1] *Schumpeter Mark I*, was proposed in *The Theory of Economic Development* (1912). This pattern of innovative activity is characterized by 'creative destruction' with technological ease of entry and a major role played by entrepreneurs and new firms in innovative activities. New entrepreneurs enter an industry with new ideas and innovations, launch new enterprises which challenge established firms, and continuously disrupt the current ways of production, organization and distribution, thus wiping out the quasi rents associated with previous innovations. The second pattern, labelled subsequently *Schumpeter Mark II*, was proposed in *Capitalism, Socialism and Democracy* (1942). In this work Schumpeter discussed the relevance of the industrial R&D laboratory to

[1] Phillips (1971), Nelson and Winter(1982) and Kamien and Schwartz(1982)

technological innovation and the key role of large firms. This pattern of innovative activity is characterized by 'creative accumulation' with the prevalence of large established firms and the presence of relevant barriers to entry for new innovators. With their accumulated stock of knowledge in specific technological areas, their competencies in R&D, production and distribution and their relevant financial resources, they create relevant barriers to entry to new entrepreneurs and small firms.

The Schumpeterian Mark I and Mark II patterns of innovation could also be labelled 'widening' and 'deepening'. A widening pattern of innovative activities is related to an innovative base which is continuously growing through the entry of new innovators and to the erosion of the competitive and technological advantages of the established firms. A deepening pattern of innovation, on the other hand, is related to the dominance of a few firms which are continuously innovative through the accumulation over time of technological and innovative capabilities (Malerba and Orsenigo, 1995).

Recent research (see Klepper, 1997, in this volume) has clearly shown that during the evolution of industries changes may occur in Schumpeterian patterns of innovations. According to an industry life cycle view, the Schumpeter Mark I pattern of innovative activities may turn into Schumpeter Mark II. Early in the history of an industry, when technology is changing very rapidly, uncertainty is very high and barriers to entry are very low, new firms are the major innovators and are the key elements in industrial dynamics. When the industry develops and eventually matures and technological change follows well-defined trajectories, economies of scale, learning curves, barriers to entry and financial resources become important in the competitive process. Thus, large firms with monopolistic power come to the forefront of the innovation process (Utterback and Abernathy, 1975; Gort and Klepper, 1982; Klepper, 1996). Conversely, in the presence of major technological and market discontinuities, a Schumpeter Mark II pattern of innovative activities may be replaced by a Schumpeter Mark I. In this case, a stable organization characterized by incumbents with monopolistic power is displaced by a more turbulent one with new firms which are using the new technology or focusing on the new demand (Henderson and Clark, 1990; Christensen and Rosenbloom, 1995).

## 2.2 The Empirical Evidence on Sectoral Patterns of Innovation

Is it possible to observe empirically across sectors and across countries patterns of innovation that more closely resemble the Schumpeter Mark I and the Schumpeter Mark II model? Malerba and Orsenigo (1995, 1996a–c) have examined this issue using patent data. First, the OTAF-SPRU database on patents granted by the American Patent Office has been elaborated at the firm level for four European countries (Germany, France, the UK and Italy) for the period 1969–1986, considering 33 technological classes (Malerba and Orsenigo, 1995). Second, a similar analysis at the firm level has been performed using a different dataset: the EPO (European Patent Office) database on patent applications for six countries (Germany, France, the UK, Italy, the USA and Japan) for the period 1978–1991 (Malerba and Orsenigo, 1996a–c). With the EPO database, patent data have been aggregated into 48 main technological classes and one residual class. These classes have been built from 12-digit subclasses of the International Patent Classification (IPC) grouping them according to the specific application of patents (EPO-CESPRI classification). Economic data have been gathered on the size of firms in term of employees in 1984 for the OTAF-SPRU database and in 1991 for the EPO-CESPRI database. Firms which are part of business groups have been treated as individual companies.[2]

The OTAF-SPRU and the EPO-CESPRI data sets give remarkably consistent results. Thus, for sake of simplicity, in what follows reference will be made only to the EPO-CESPRI database, unless otherwise specified.

Patterns of innovative activities have been analysed on the basis of a set of indicators which attempt to capture some of the essential features of the two Schumpeterian 'models'. Specifically, Malerba and Orsenigo developed measures of the following characteristics of innovative activities:

- Concentration and asymmetries among firms of innovative activities.
- Size of the innovating firms.
- Change over time in the hierarchy of innovators.
- Relevance of new innovators as compared to established ones.

The first two sets of indicators—concentration and firm size—have been conventionally used in the traditional discussions of the so-called 'Schumpeterian hypotheses': they are meant to measure the extent to which innovative activities tend to be concentrated in a few firms or are evenly distributed across a large number of firms, and whether large firms or small

[2] For the EPO database, as far as the USA is concerned, 133 475 patents and 11 476 firms have been considered; for Germany 108 118 patents and 8495 firms; for France 43 986 patents and 5671 firms; for the UK 35 175 patents and 6055 firms; for Italy 15 175 patents and 3803 firms; and for Japan 81 217 and 3990 firms. In addition, for the four European countries data on the size of the innovators have been gathered: 56% of the German firms, 49% of the French firms, 34% of the British firms and 51% of the Italian firms have been covered. For details about the construction of the datasets, see Malerba and Orsenigo (1995, 1996a).

TABLE 1 Concentration of innovative activities

| Concentration ratio of the top four innovators (C4) | |
|---|---|
| **High C4** | **Low C4** |
| Organic chemicals | Clothing |
| Macromolecular compounds | Furniture |
| Agricultural chemicals | Agriculture |
| Aircraft | Mining |
| Computers | Chemical apparatus |
| Telecommunications | Industrial automation |
| Nuclear technology | Industrial machinery and equipment |
| | Mechanical engineering |
| | Measuring equipment |

TABLE 2 Asymmetries among firms

| Herfindhal index (HERF) | |
|---|---|
| **High HERF** | **Low HERF** |
| Organic chemicals | Clothing |
| Macromolecular compounds | Furniture |
| Miscellaneous chemical compounds | Agriculture |
| Electronic components and telecommunications | Mining |
| | Metallurgy |
| | Industrial automation |
| | Industrial machinery |
| | Material handling apparatus |
| | Civil engineering |
| | Mechanical engineering |
| | Mechanical and electric technologies |
| | Sports |

firms are the main source of innovation in any particular technological class. The other two sets of measures aim to shed light on the degree of 'stability' and 'creative accumulation' or 'dynamism' and 'creative destruction' in the organization of innovative activities. In particular, these indicators try to identify dimensions related to the role of new innovators and the stability in the list of the main innovators of our time.

Thus, for each of the technological classes, indicators of the patterns of innovative activities for the six countries have been constructed using patent data. Tables 1–5 show those technological classes for which an indicator is consistently high or low in all the countries.

TABLE 3 Size of the innovating firms

| Share of total patent applications applied for by firms with more than 500 employees (SIZE) | |
|---|---|
| High SIZE | Low SIZE |
| Inorganic chemicals | Clothing |
| Organic chemicals | Furniture |
| Macromolecular compounds | Agriculture |
| Adhesives | Sports |
| Agricultural chemicals | |
| Computers and other office equipment | |

TABLE 4 Stability in the hierarchy of innovators

| Spearman rank correlation coefficient between firms innovating in 1978–1985 and firms innovating in 1986–1991 (SPEATOT) | |
|---|---|
| High SPEATOT | Low SPEATOT |
| Gas and oil | Clothing |
| Organic chemicals | Furniture |
| Macromolecular compounds | Agriculture |
| New materials | Chemical processes |
| Adhesives | Machine tools |
| Drugs | Industrial automation |
| Aircraft | Civil engineering |
| Electronic components | Sports |
| Telecommunications[a] | |

[a]Malerba and Orsenigo (1994, 1996) also computed a measure of the stability of the hierarchy of only those firms which innovate continuously over time (Spearman rank correlation coefficient between the hierarchies of firms innovating both in 1978–1985 and 1986–1991: SPEACORE). The difference between SPEATOT and SPEACORE is that the first indicator also considers firms entering and exiting from the population of innovators. Thus, when turbulence is generated by new entrants and exiters but incumbent firms mantain over time a stable ranking, one might observe technological classes characterized by high values of SPEACORE but low values of SPEATOT. SPEACORE has a low positive value or a negative value in furniture, agriculture, mining, agricultural chemicals, chemical processes and machine tools, while it has a high positive value in organic chemicals, macromolecular compounds, computers and office equipment.

## 2.3 Schumpeterian Patterns of Innovations are Technology-specific

Schumpeterian patterns of innovation are identified by the existence of specific and systematic relationships between these measures. In particular, the Schumpeter Mark I (widening) model should be characterized by low concentration and asymmetries in innovative activities, low stability in the

TABLE 5 Technological entry

| Share of patent applications by firms applying for the first time in a given technological class in the period 1986–1991 over the total number of patents in the same period (ENTRY)[a] | |
|---|---|
| High ENTRY | Low ENTRY |
| Clothing | Organic chemicals |
| Furniture | Macromolecular compounds |
| Mining | Electronic components |
| Chemical processes | Consumer electronics |
| Machine tools | Telecommunications |
| Civil engineering | |
| Lighting systems | |
| Sports | |

[a]This indicator measures innovative entry and not entrepreneurial birth: a new innovator may in fact have been around for quite a long time.

ranking of innovators, and high entry and small size of new innovators. Conversely, the Schumpeter Mark II (deepening) model should be characterized by high concentration and asymmetries in innovative activities, high stability of the hierarchy of innovators, and low entry and large size of new innovators.

Indeed, coherent relationships exist between these indicators. First, correlation analysis for the various technological classes shows in all countries a positive correlation between concentration (C4) and asymmetries (HERF), stability of innovators' hierarchy (SPEATOT and SPEACORE) and (though to a lesser extent) the size of innovating firms (SIZE), and a negative correlation between these measures and entry of new innovators (ENTRY) (see Table 6). Second, principal component analysis performed for all the technological classes identifies in all countries one dominant factor which captures a large fraction of the variance.[3] This factor discriminates in all countries between measures of concentration and asymmetries (C4 and HERF) and stability of the hierarchy of innovators (SPEATOT) on the one hand, and the variable ENTRY on the other. In other words, this component captures quite neatly the distinction between Schumpeter Mark I and Schumpeter Mark II technological classes. Thus, one can conclude that the relationships between the various indicators of the patterns of innovation are actually related to the two archetypical models and that the latter discriminate significantly between technological classes. Schumpeter Mark I

[3] These values are 49% for Japan, 58% for the USA, 68% for Germany, 69% for France, 75% for the UK, 68% for Italy and 72% for the four European countries considered together.

TABLE 6 Correlation between the indicators of the patterns of innovative activities in each country

| | C4 | HERF | SIZE | SPEATOT | SPEACORE | ENTRY |
|---|---|---|---|---|---|---|
| Germany | | | | | | |
| C4 | 1 | 0.89881 | 0.33844 | 0.36844 | 0.57346 | −0.57813 |
| HERF | | 1 | 0.09239 | 0.28063 | 0.48148 | −0.46861 |
| SIZE | | | 1 | 0.36835 | 0.22132 | −0.37634 |
| SPEATOT | | | | 1 | 0.30587 | −0.84354 |
| SPEACORE | | | | | 1 | −0.53782 |
| ENTRY | | | | | | 1 |
| France | | | | | | |
| C4 | 1 | 0.92008 | 0.47724 | 0.49505 | 0.12514 | −0.42053 |
| HERF | | 1 | 0.33259 | 0.51173 | 0.12194 | −0.35631 |
| SIZE | | | 1 | 0.32049 | −0.01212 | −0.35009 |
| SPEATOT | | | | 1 | 0.36538 | −0.83329 |
| SPEACORE | | | | | 1 | −0.33577 |
| ENTRY | | | | | | 1 |
| UK | | | | | | |
| C4 | 1 | 0.83724 | 0.78668 | 0.6277 | 0.38625 | −0.70286 |
| HERF | | 1 | 0.6824 | 0.48092 | 0.3251 | −0.52961 |
| SIZE | | | 1 | 0.78237 | 0.53917 | −0.86022 |
| SPEATOT | | | | 1 | 0.44551 | −0.84832 |
| SPEACORE | | | | | 1 | −0.47762 |
| ENTRY | | | | | | 1 |
| Italy | | | | | | |
| C4 | 1 | 0.88115 | 0.64289 | 0.57945 | 0.37243 | −0.35003 |
| HERF | | 1 | 0.53631 | 0.52956 | 0.37258 | −0.40617 |
| SIZE | | | 1 | 0.59229 | 0.19664 | −0.37144 |
| SPEATOT | | | | 1 | 0.46768 | −0.65505 |
| SPEACORE | | | | | 1 | −0.53974 |
| ENTRY | | | | | | 1 |
| Japan | | | | | | |
| C4 | 1 | 0.84348 | | −0.09938 | 0.26162 | −0.26614 |
| HERF | | 1 | | −0.23929 | 0.20355 | −0.16748 |
| SPEATOT | | | | 1 | 0.27068 | −0.80604 |
| SPEACORE | | | | | 1 | −0.29935 |
| ENTRY | | | | | | 1 |
| USA | | | | | | |
| C4 | 1 | 0.90887 | | 0.03358 | 0.39853 | −0.4868 |
| HERF | | 1 | | −0.06819 | 0.34564 | −0.37406 |
| SPEATOT | | | | 1 | 0.53147 | −0.76739 |
| SPEACORE | | | | | 1 | −0.69282 |
| ENTRY | | | | | | 1 |

Source: EPO—Center for Research on Internationalization (CESPRI, Bocconi University) database.

TABLE 7 Taxonomy of patterns of innovative activities

| Schumpeter Mark I technological classes | Schumpeter Mark II technological classes |
|---|---|
| Clothing and shoes | Gas, hydrocarbons and shoes |
| Furniture | Organic chemicals |
| Agriculture | Macromolecular compounds |
| Chemicals | Biochemicals, bio- and genetic engineering |
| Physical processes | Aircraft |
| Medical preparation | Engines, turbines and pumps |
| Chemical processes for food and tobacco | Laser technology |
| Machine tools | Optics and photography |
| Industrial automation | Computers and other office equipment |
| Industrial machinery and equipment | Electronics components |
| Railways and ships | Telecommunications |
| Material handling apparatus | Multimedia systems |
| Civil engineering and infrastructure | Ammunition and weapons |
| Mechanical engineering | Nuclear technology |
| Mechanical and electric technologies | |
| Household electric appliances | |
| Lighting systems | |
| Measurement and control instruments | |
| Sports and toys | |
| Others | |

technological classes are to be found especially in the 'traditional' sectors, in the mechanical technologies, in instruments and in the white electric goods industry. Conversely, most of the chemical and electronic technologies are characterized by the Schumpeter Mark II model.

A cross-country comparison of the Schumpeterian patterns of innovation shows that these patterns of innovative activities are technology specific: strong similarities are observed in the same technological class across countries. This is shown in various ways. The correlation coefficients for each indicator in the 49 technological classes across countries indicate that in the same technological class, concentration, asymmetries, stability of the hierarchy of innovators and the role of new innovators tend to have the same values across countries. Moreover, the characterization of a technological class as Schumpeter Mark I or Schumpeter Mark II is very similar across countries. Principal component analysis shows that many of the classes which were included in the Schumpeter I and Schumpeter II groups are quite similar in all countries. Specifically, 19 technological classes are consistently in the Schumpeter Mark I camp, while 15 technological classes are consistently in the Schumpeter Mark II camp (see Table 7).

The sector specificity of the patterns of innovative activities emphasizes two major points. First, some features of the technological environments are

TABLE 8 Patterns of innovative activities across countries (average over 49 technological classes)

| | | Germany | France | UK | Italy | Japan | USA |
|---|---|---|---|---|---|---|---|
| C4 | Av | 36.70 | 32.90 | 34.00 | 37.60 | 34.90 | 29.50 |
| | Std | 19.70 | 15.20 | 18.60 | 20.10 | 16.50 | 17.70 |
| HERF | Av | 0.07 | 0.05 | 0.07 | 0.08 | 0.07 | 0.06 |
| | Std | 0.08 | 0.05 | 0.10 | 0.09 | 0.08 | 0.09 |
| SIZE | Av | 52.30 | 43.90 | 45.90 | 33.60 | – | – |
| | Std | 15.80 | 14.90 | 18.20 | 19.60 | – | – |
| SPEATOT | Av | –0.13 | –0.29 | –0.36 | –0.35 | –0.06 | –0.23 |
| | Std | 0.17 | 0.20 | 0.19 | 0.33 | 0.26 | 0.19 |
| SPEACORE | Av | 0.55 | 0.46 | 0.47 | 0.37 | 0.56 | 0.52 |
| | Std | 0.20 | 0.21 | 0.20 | 0.50 | 0.26 | 0.18 |
| ENTRY | Av | 0.33 | 0.45 | 0.46 | 0.65 | 0.41 | 0.34 |
| | Std | 0.18 | 0.19 | 0.20 | 0.20 | 0.22 | 0.18 |

Source: EPO-CESPRI database.

common to groups of industries. Second, they are to some extent invariant with respect to the institutional environment.

However, country differences emerge in some technological classes as a result of the working of either specific institutional factors related to a national system of innovation or the presence of a firm or an industry with a peculiar history. Moreover, in the EPO data set some countries—Germany, Japan and to a lesser extent the USA—are closer to a Schumpeter Mark II model, as opposed to Italy, typically a Schumpeter Mark I country. Japan emerges as a rather concentrated and stable country as opposed to Europe (see Table 8).[4]

## 3. *Technological Regimes and Patterns of Innovative Activities*

### 3.1 The Technological Regime

The empirical evidence previously discussed suggests the existence of *differences across sectors* in the patterns of innovation ('Schumpeter Mark I'

[4] The USA and Europe show similar features. The USA is characterized by low degrees of concentration (C4) and asymmetry (HERF), low innovative entry, high degrees of stability of the ranking of innovators within the core of companies which innovate continuously over time (SPEACORE); Europe is on average less concentrated and stable than the USA. If the comparison is made considering individual European countries, Germany has several features of a Schumpeter Mark II country. Conversely, Italy exhibits features of a Schumpeter Mark I pattern, despite a very high concentration. The other countries fall in between these extremes: innovative activities are widely diffused in a relatively stable group of innovators. The UK and France are quite similar, but the former is characterized by a low stability of the ranking of innovators.

versus 'Schumpeter Mark II' models) and *similarities across countries* in the patterns of innovation for a specific technology

Our general conjecture is that 'technological imperatives' and, more generally, broad factors related to specific ways of accumulating knowledge play a major role in determining the specific pattern of innovative activities in a technological class across countries. Specifically, we propose that the observed sectoral patterns of innovative activities are related to the nature of the relevant '*technological regime*'. The notion of technological regime dates back to Nelson and Winter (1982) and provides a description of the technological environment in which firms operate. More generally, Malerba and Orsenigo (1990, 1993) have proposed that a technological regime is a particular combination of some fundamental properties of technologies: opportunity and appropriability conditions; degrees of cumulativeness of technological knowledge; and characteristics of the relevant knowledge base. Let us briefly discuss these basic dimensions.

(i) *Opportunity conditions* reflect the easiness of innovating for any given amount of resources invested in search. Four basic dimensions of opportunity can be identified: *level*, *pervasiveness*, *sources* and *variety*.

- *Level.* High opportunities provide powerful incentives to the undertaking of innovative activities, because they determine a high probability of innovating for a given amount of resources invested in search.
- *Variety.* In some cases, high levels of opportunity conditions are associated with a potentially rich variety of technological solutions, approaches and activities. This is particularly so in the early stages of an industry life cycle. As Utterback and Abernathy (1975), Dosi (1982) and Abernathy and Clark (1985), among others, have pointed out, in the *pre-paradigmatic stage* of technologies, when a dominant design has not yet been defined, firms may search in various directions and come up with different technological solutions. Later on, in the *paradigmatic stage*, when a dominant design has emerged, technical change may proceed along specific trajectories so that the variety of radically different technological solutions is reduced.
- *Pervasiveness.* In case of high pervasiveness, new knowledge may be applied to several products and markets, while in case of low pervasiveness new knowledge applies only to few (eventually one) products and markets.
- *Source.* The sources of technological opportunities markedly differ among technologies and industries. As Freeman (1982), Rosenberg (1982) and Nelson (1986), among others, have shown, in some industries

opportunity conditions are related to major scientific breakthroughs in universities. In other sectors, opportunities to innovate may often come from advancements in R&D, equipment and instrumentation, as well as from endogenous learning. In still other sectors, external sources of knowledge in terms of suppliers or users may play a crucial role.

(ii) *Appropriability conditions* summarize the possibilities of protecting innovations from imitation and of extracting profits from innovative activities. It is possible to identify two basic dimensions: *level* and *means of appropriability*.

- *Level.* Industrial sectors can be ranked according to high or low appropriability conditions (Levin *et al.*, 1987). High appropriability means the existence of ways to successfully protect innovation from imitation. Low appropriability conditions denote an economic environment characterized by widespread knowledge externalities (spillovers).
- *Means of appropriability.* Firms utilize a variety of means in order to protect their innovations, ranging from patents, to secrecy, continuous innovations and the control of complementary assets (Teece, 1986; Levin *et al.*, 1987). The effectiveness of these means of appropriability largely differ from industry to industry, thus affecting the level as well as the nature of knowledge externalities.

(iii) *Cumulativeness conditions* capture the properties that current innovations and innovative activities form the starting point for tomorrow's innovations and that today's innovative firms are more likely to innovate in the future in specific technologies and along specific trajectories than non-innovative firms. From these definitions, one can identify three different sources:

- *Learning processes and dynamic increasing returns at the technology level.* The generation of new technological knowledge builds upon what has been previously done. The cognitive nature of learning processes and past knowledge constrain current research, but also generate new questions and new knowledge.
- *Organizational sources.* Cumulativeness might be generated by the establishment of R&D facilities at a fixed cost, which then produce a relatively stable flow of innovations. More generally, however, cumulativeness is likely to be originated by firm-specific technological and organizational capabilities, which can be improved only gradually over time and thus define what a firm can do now and what it can hope to achieve in the future.

- *Success breeds success.* Finally the notion of cumulativeness can be related to the Schumpeterian intuition that critical market feedbacks link R&D investment, technological performance and profitability (Schumpeter, 1942). For instance, persistence may be simply the outcome of 'success-breeds-success' processes like those used in Nelson and Winter's (1982) models: innovative success yields profits that can be reinvested in R&D, thereby increasing the probability to innovate again.

Relatedly, cumulativeness may be observed at various levels of analysis:

- The *technological level.*
- The *firm level.* High cumulativeness at the firm level implies an implicit mechanisms leading to appropriability of innovations.

In case of low appropriability conditions and knowledge spillovers, however, it is also possible to observe cumulativeness at a more aggregate level, such as:

- The *sectoral level.* In this case the relevant knowledge base for innovation diffuses widely across firms in a sector.
- The *local level.* In this case high cumulativeness within specific locations is more likely to be associated with low appropriability conditions and *spatially* localized knowledge spillovers.

(iv) The ***knowledge base*** refers to the properties of the knowledge upon which firms' innovative activities are based. Two major characteristics of the knowledge base may be identified: ***the nature of knowledge*** and ***the means of knowledge transmission and communication***.

**Nature of Knowledge.** Technological knowledge involves various degrees of specificity, tacitness, complexity and independence (Winter, 1984).

- *Generic versus specific*: in a sector the knowledge base may be of a generic nature or specific to well-defined application domains.
- *Tacit versus codified*: in a sector the knowledge base underpinning innovative activities may show varying degrees of tacitness.
- *Complex versus simple*: similarly, the relevant knowledge base may show relatively high or low degrees of complexity in terms of integration of different scientific and engineering disciplines and technologies needed for innovative activities and variety of competencies (such as R&D,

manufacturing equipment, engineering and production and marketing) needed for innovative activities.
- *Independent versus systemic*: the knowledge relevant to innovative activities may be easily identifiable and isolated or rather it may be part of (and therefore embedded within) a larger system, and therefore difficult to decompose in 'chunks'.

Some of these features of knowledge may change during the evolution of a specific sector or technology (degree of codification, independence and complexity).

**Means of Knowledge Transmission.** The characterization of a technology according to each of these four dimensions strongly affects the ways firms can effectively get access to the relevant knowledge. One can argue that the more knowledge is ever changing, tacit, complex and part of a larger system, the more relevant are informal means of knowledge transmission, like 'face-to-face' talks, personal teaching and training, mobility of personnel and even acquisition of entire groups of people. Moreover, it should also be stressed that such means of knowledge transmission are extremely sensitive to the distance between agents. On the other hand, the more knowledge is standardized, codified, simple and independent, the more relevant are formal means of knowledge communication, such as publications, licenses, patents and so on. In such circumstances, one can argue that geographical proximity does not play a crucial role in facilitating the transmission of knowledge across agents. A fundamental implication of this argument is that the nature of knowledge strongly affects the way technological opportunities and knowledge externalities are transmitted among distant firms (Breschi and Malerba, 1996).

The notion of technological regime has indeed proved to be useful in providing a framework for interpreting the substantial body of empirical evidence on the sectoral organization of innovative activities discussed above, in particular the type of Schumpeterian pattern of a sector. What follows summarizes the main hypotheses and empirical results about the links between technological regimes and the patterns of innovative activities.

## 3.2 Technological Regimes Affect the Sectoral Patterns of Innovative Activities

**3.2.1 The Main Hypotheses.** The notion of technological regime also provides the basis of an explanation of the diversity in the patterns of innovation across sectors and technologies. It has been noted that the introduction of even rough proxies of opportunity and appropriability conditions significantly improves the performance of econometric tests on the relationships between market structure (e.g. firm size and degrees of concentration) and innovation (Cohen and Levin, 1989). Malerba and Orsenigo (1990, 1993) discuss the main relationships between the variables which define a technological regime and the various measures of the sectoral patterns of innovation.

*Ceteris paribus*, technological regimes characterized by high levels of *technological opportunities* are expected to show patterns of innovation characterized by a remarkable turbulence in terms of technological entry, a high instability in firms' hierarchies and a tendency towards sectoral concentration (and therefore a low number of innovators). High technological opportunities allow for the continuous entry of new innovators. However, if successful, established firms may also end up gaining a substantial leap in their relative competitiveness, thus leading to the elimination from the market of less successful innovators. Conversely, conditions of low opportunities limit innovative entry and restrict the innovative growth of successful established firms. As a consequence, a higher stability of the major innovators and a less concentrated industrial structure may emerge.

High degrees of *technological appropriability*, by limiting the extent of knowledge spillovers and by allowing successful innovators to maintain their innovative advantages, are expected to result in a relatively higher level of industrial concentration and a lower number of innovators. Conversely, by discouraging investments in innovative activities and by determining a wider diffusion of the relevant knowledge across firms, low appropriability conditions are more likely to lead to a sectoral structure characterized by the presence of a large population of innovators.

High levels of *technological cumulativeness* at the firm level are expected to be associated with *persistence* in innovative activities. At the sectoral level, technological cumulativeness and persistence are expected to be associated with a rather high degree of stability in the hierarchy of the innovative firms and low rates of innovative entry. In such circumstances, the selection process favours established technological leaders. Existing innovators accumulate technological knowledge and capabilities and build up innovative advantages which play a relevant role in affecting their competitiveness and act as powerful barriers to the entry of new innovators.

The role of the *knowledge base* on patterns of innovative activity is more complex, and plays a major role in affecting diversification, specialization and integration of innovative activities. We give here a brief discussion; a more detailed discussion is given in Malerba and Orsenigo (1993). One could argue that a *highly tacit* knowledge may lead firms to develop internal codes and channels of communication, while making imitation weaker or the possibility of transferring this knowledge to other firms and institutions more difficult. A *codified* knowledge base may, on the contrary, induce specialization and division of labour (Arora and Gambardella, 1994). *Pervasiveness* may imply opportunities for technological diversification through the application of the core technological knowledge to a variety of products and markets. Conversely, lack of pervasiveness, particularly if coupled with high degrees of cumulativeness, may entail a tendency towards product and market specialization. Thus one may expect that diversified companies will tend to emerge in regimes characterized by pervasive opportunities and low cumulativeness, whilst specialist companies are more likely to emerge in highly cumulative and non-pervasive technologies. *Complexity* of the knowledge base may highlight other issues. One would expect that the more complex the knowledge base is, the stronger is the need for firms to develop mechanisms for the integration of the various components of knowledge. In general, a highly complex but separable and codified knowledge base, coupled with high opportunity and appropriability conditions, may induce firms to develop external networks composed of complementary specialist firms co-existing with system integrators. In the case of separable but highly tacit and appropriable knowledge, on the other hand, firms may be induced to develop long-term strategic alliances, concerning complementary innovative activities to be implemented in common and shared. Finally, low appropriability conditions and high degrees of tacitness and indivisibility of the knowledge base may favour strategies and organizational solutions directed towards full control and integration, the development of complementary assets and strong internal codes of communication (Teece, 1986; Von Hippel, 1988).

From the above discussion it is possible to link the features of a technological regime in terms of opportunity, appropriability and cumulativeness conditions to the specific Schumpeterian pattern of innovative activities. Keeping the archetypical distinction between Schumpeter Mark I and Mark II proposed previously, we may expect that Schumpeter Mark II patterns of innovation (high concentration of innovative activities, low number of innovators, low rates of entry and stability in the hierarchy of innovators) are determined by high opportunity, appropriability and cumulativeness (at the firm level) conditions. Note that if technological cumulativeness is low, the resulting dynamics of the innovators' population may show higher degrees of sectoral instability, by lowering the barriers to entry of new potential innovators. On the other hand, we may expect

Schumpeter Mark I patterns of innovation (low concentration of innovative activities, large number of innovators, high rates of entry and high instability in the hierarchy of innovators) in situations of high opportunity, low appropriability and low cumulativeness (at the firm level) conditions. Firms' technological advantages may be quite large, but innovations are neither kept proprietary nor lasting enough to generate a technological lead. The limited levels of cumulativeness at the firm level soon render innovative advantages obsolete, thus leaving room for imitation and the entry of new innovators. Lower opportunity conditions just reinforce the Schumpeter Mark I pattern. Notice, however, that the interplay between these variables may not be linear and may generate complex dynamic patterns. For example, when high cumulativeness is coupled with high opportunities, a 'lucky' entrant may progress very rapidly by exploiting cumulativeness and end up disrupting the existing rank of innovators.

The empirical evidence on the remarkable similarity in the sectoral patterns of innovative activities across countries that has been presented above provides a first hint and indirect evidence of the relevance of technological regimes in determining sectoral invariances in the patterns of innovative activities, as long as opportunity, appropriability and cumulativeness conditions are similar across countries. Empirical evidence on the similarity of some of the dimensions of appropriability and cumulativeness across advanced industrialised countries is now emerging. Malerba and Orsenigo (1990) and Heimler *et al.* (1993) have compared the results of the Yale survey on appropriability and opportunity conditions in several sectors in the USA (Levin *et al.*, 1987) with the results of two similar surveys on appropriability and opportunity conditions in a set of similar sectors of the Italian industry. They have found that for two countries as different as the USA and Italy, the levels and means of appropriability and a simple measure of cumulativeness are quite similar for the same industry in the two countries. The ability to generate and exploit opportunity conditions is, however, less similar in these two countries, because this ability is related to the level and range of university research, the presence and effectiveness of science–industry bridging mechanisms, vertical and horizontal links among local firms, user–producer interaction, and the types and level of firms' innovative efforts (Nelson, 1992).

### 3.2.2 Quantitative Evidence

*Cumulativeness, Persistence and Sectoral Patterns of Innovative Activities.* Within a very simple statistical framework, if innovation is considered as a random shock in a firm's technological domain, some measure of serial correlation in innovative activities can be interpreted as a proxy for 'persistence' and the notion of cumulativeness may be interpreted as persistence in innovative activities. Thus to the extent that technological cumulativeness, organizational capabilities and market feedbacks are not observable, firm-level serial correlation can be considered as an indicator of the persistence of innovative activities generated by technology, competence and market-feedback processes. Malerba *et al.* (1997) calculated indicators of firm-level innovative persistence, again using the OTAF-SPRU database for five European countries (Germany, the UK, France, Italy and Sweden). These indicators are obtained by exploiting the microeconomic information contained in the data. They estimated for each technological class in each country (165 regressions in all), the dynamic panel data model with variable intercept:

$$P_{it} = aP_{it-1} + b_i + u_{it} \qquad i = 1, \ldots, N \text{ and } t = 1, \ldots, T \qquad (1)$$

where $N$ is the number of firms $i$ in the panel in a given technological class in a given country; $T$ is the number of years $t$ (18) in the panel; $a \leq 1$ is a time-invariant coefficient of firm-level autocorrelation in patenting, considered to be the same for all firms in a specific sector; $b$ is a time-invariant, firm-specific effect.[5] The instrumental variable estimator for the autocorrelation coefficient is the indicator of persistence. The variance of the firm-specific random effects provides an estimate of the heterogeneity in the population of innovators.

Malerba *et al.* (1997) examined the relationships between persistence, heterogeneity and the observed patterns of innovative activities across sectors and countries. The dependent variables are the index of technological concentration (HERF); the stability of the rank of innovators (SPEATOT for the whole sample and SPEACORE for the firms that innovated consistently over the entire period); and the innovative intensity (AVSTOCK = average number of patents per firm).[6]

The results of the analysis by Malerba *et al.* (1997) show that persistence strongly affects the patterns of innovative activities across countries and sectors. First of all persistence is closely related to heterogeneity of innovative firms. Second, persistence positively affects concentration and the stability of the rank of persistent innovators (who innovate during the whole period considered). Finally, persistence is positively associated with innovative intensity in terms of average number of patents per firm.

[5] The standard assumptions on the disturbances and the firm-specific random effects are made.

[6] Note that this variable is not really an indicator of the rates of innovation, but only of the intensity of patenting activities. This indicator is obviously influenced by the total number of patents, but also by the total number of firms within a technological class. Thus, similar values of AVSTOCK might reflect simply different patterns of innovation.

In sum, these results confirm that persistence of innovative activities is associated with a typical Schumpeter Mark II model. Thus, cumulativeness leads to processes of creative accumulation and to a highly concentrated and stable structure of innovators, where a few continuously innovating firms hold a large share of patents in a given technological class.

These results give quantitative support to the theoretical models that have examined the effects of serial correlation in innovative activities upon the patterns of technical change and industrial dynamics. In particular, Winter (1984) showed via simulations that in a routinized regime innovative persistence generates high rates of innovation, concentration and stability in the ranking of innovators, and low innovative turnover as measured by the rates of entry of new innovators and exit of old innovators. Similar results were obtained by Dosi *et al.* (1995), who examined through simulations the effects of a cumulative learning regime on market shares and the entry and exit of firms.

*Technological Regimes and Schumpeterian Patterns of Innovation.* A more direct attempt at trying to assess directly the relationships between the variables that define technological regimes on the one hand and the Schumpeterian patterns of innovation on the other has been provided by Breschi *et al.* (1996). Two major sources of data have been used. First, the EPO-CESPRI database on patent applications by firms of three countries (Italy, West Germany and the UK) for the period 1978–1991 has been used to construct the various measures of the sectoral patterns of innovative activities. Five measures of patterns of innovative activities were considered:

- innovative concentration (the Herfindahl index, HERF, and the concentration ratio, C4);
- turbulence (technological entry, ENTRY and the degree of stability of the hierarchy of innovators, SPEATOT);
- a synthetic measure of the sectoral patterns of innovative activities (SCHUMPATTERN).[7]

Second, data on industry-specific technological conditions (i.e. technological regimes) were drawn from the recent PACE (Policy Appropriability and Competitiveness for European Enterprises) questionnaire survey coordinated by the Merit Institute (The Netherlands). The survey was addressed to 713 R&D executives from the European Union's largest

[7] In order to group technological classes according to measures of Schumpeterian patterns of innovative activities, principal component analysis has been performed for all the 49 technological classes (see Malerba and Orsenigo, 1996). The individual scores resulting from such analysis have been used to construct SCHUMPATTERN.

manufacturing firms with the aim of obtaining their opinions on and rating (on a five-point Likert scale) of a broad range of innovation-related issues: goals of innovation, external sources of knowledge, public research, methods to protect innovations, government programmes to support innovation, and barriers to profiting from innovation. The unit of analysis was the line of business, as defined by four-digit ISIC sectors. Overall, the 713 sample business units were operated by 414 firms in 101 manufacturing sectors. This latter data set has been used to compute indicators of the variables which define a technological regime.

Only a few of the dimensions of the technological regimes discussed above have been captured by this data set. However, these dimensions allowed Breschi *et al.* to represent in a stylized way some of the relevant features of a technological regime. *Opportunity conditions* have been captured only in terms of the scientific and technological ferment in an industry, measured by sectoral R&D intensity. *Appropriability conditions* are measured with responses to questions concerning the effectiveness of two methods used by firms to prevent competitors from copying product and process innovations: patents and secrecy. The variable appropriability is for each individual respondent the sum of scores received by each of these two mechanisms for either process or product innovations. *Cumulativeness conditions* are measured by the importance of frequent technological improvements in making product innovations difficult or commercially unprofitable to imitate. The score received by this question—cumulativeness—can therefore be assumed to be a proxy of the degree to which technical advances in a given industry take place in a 'cumulative' way. Finally, one feature of the *knowledge base*—its generic or specific character—is captured by the role of basic and applied sciences in fostering innovation in an industry. Survey respondents were asked to rate the importance to the progress of their unit's technological base of ten fields of basic and applied science over the past ten years. The variable BASICSCIENCE represents for each individual respondent the sum of scores received by the fields of basic science: biology, materials science, chemistry, medical and health, physics, chemical engineering, mathematics. The variable APPLIEDSCIENCE represents the sum of scores received by the fields of applied science: electrical engineering, computing science and mechanical engineering.

The role played by technological regimes has been tested by performing regression analysis (OLS) using the various measures of Schumpeterian patterns of innovation as dependent variables. The main results which emerge from such analysis can be summarized as follows.

1. Variables related to technological regimes are individually significant at the conventional statistical level and have the expected sign. In particular, appropriability, cumulativeness and BASICSCIENCE are significantly and positively related to the concentration ratio of innovators (C4), asymmetries among innovators (HERF) and stability in the hierarchy of innovators (SPEATOT), as well as to SCHUMPATTERN, while they are negatively related to entry of innovative firms (ENTRY). An interesting result emerges in relation to the dimension of the knowledge base considered in the analysis. APPLIEDSCIENCE is significantly and negatively related to all above-mentioned measures of sectoral patterns of innovation except ENTRY. This result suggests that a knowledge base related to basic sciences leads to a Schumpeter Mark II pattern because firms need to have absorptive capabilities and large R&D laboratories able to transform advances in basic sciences into new products and process. Established innovators may be better suited to these types of opportunities. On the other hand, advances in applied sciences are already closer to a possible innovative exploitation and are more focused on specific applications. They may be easily 'used' by new entrants (as well as by established firms) and are therefore associated with a Schumpeter Mark I pattern of innovation.
2. All principal results concerning the significance and importance of industry characteristics hold irrespective of whether or not other variables intended to capture the level of entry barriers—such as the ratio between industry turnover and total number of operating firms—are included in the specification.
3. Tests of the joint significance of opportunity, appropriability and cumulativeness variables reject the null hypothesis, thus providing further confirmation of the important influence of technological characteristics on Schumpeterian patterns of innovation.
4. The ratio of explained variance significantly increases when dummy variables are included in the specification to capture fixed-country effects, thus suggesting that the relationship between technological regimes and Schumpeterian patterns of innovation is fundamentally mediated by the specific features of each national system of innovation.

In conclusion, these results confirm that technological regimes, as represented by survey-based measures of technological opportunity, appropriability and cumulativeness conditions, have a very important and independent impact on the way innovative activities are structured across different industries.

## 4. *Some Further Results on Patterns of Innovative Activities*

In addition to the basic distinction between Schumpeterian patterns of innovative activities and to the relationship between technological regimes and Schumpeterian patterns, other empirical analyses have been conducted in order to explore specific dimensions of patterns of innovative activities. In particular, technological entry and exit, the spatial dimensions of innovative activities, and sectoral systems of innovation and firm behaviour have been examined.

### 4.1 Technological Entry and Exit

A key research question in trying to examine patterns of innovative activities is to disentangle 'turbulence' because the population of innovators changes substantially over time, through birth and death processes. Analysing technological entrants and exiters in the period 1987–1991 with respect to the period 1978–1986 for six countries (the USA, Japan, Germany, France, the UK and Italy) for 49 technological classes, Malerba and Orsenigo (1996) have found that new entrants in terms of EPO patents are smaller firms than persistent innovators in economic terms, whilst exiters are sometimes bigger. Both entrants and exiters, however, are relatively small innovators with respect to persistent innovators in terms of the share of patents they hold. Technological gross entry and exit has to be decomposed, however, into two components: 'new' entry and 'real' exit and 'lateral' entry and exit. The first class consists of totally new innovators that enter for the first time in the innovation scene or innovators that disappear from it. However, entrants in any one technological class may well have innovated before in a different technological class, and are diversifying technologically, expanding the range of technologies in which they are active and eventually abandoning old technologies. Similarly exiters may well start (or continue) to innovate in a different technology. As a consequence turbulence in innovative activities is generated by four types of actors: new entrants, lateral entrants, real exiters and lateral exiters.

From the EPO-CESPRI database it is possible to claim that the patterns of new technological entry and real technological exit are very similar to each other. The same holds for the patterns of lateral entry and lateral exit. Conversely, new entry and real exit are quite distinct from lateral entry and exit. New entrants and real exiters are usually firms of smaller economic size with few patents each. Lateral entrants and lateral exiters are usually firms of larger economic size engaged in a process of technological diversification (see Tables 9 and 10).

TABLE 9 Technological entry in 1987–1991 with respect to firms patenting in this period

| | G | F | UK | I | USA | J | Av. | SD |
|---|---|---|---|---|---|---|---|---|
| *Technological entry: share of firms* | | | | | | | | |
| Gross entry rate/total innovators | 0.63 | 0.69 | 0.70 | 0.80 | 0.67 | 0.69 | 0.70 | 0.05 |
| Lateral entry rate/total innovators | 0.29 | 0.26 | 0.25 | 0.20 | 0.26 | 0.36 | 0.27 | 0.05 |
| New entry rate/total innovators | 0.34 | 0.43 | 0.46 | 0.60 | 0.42 | 0.33 | 0.43 | 0.10 |
| Lateral entry/gross entry | 0.46 | 0.38 | 0.35 | 0.26 | 0.38 | 0.52 | 0.39 | 0.09 |
| *Technological entry: share of patents* | | | | | | | | |
| Gross entry rate/total innovators | 0.30 | 0.40 | 0.43 | 0.61 | 0.32 | 0.38 | 0.41 | 0.11 |
| Lateral entry rate/total innovators | 0.14 | 0.17 | 0.16 | 0.19 | 0.13 | 0.22 | 0.17 | 0.03 |
| New entry rate/total innovators | 0.16 | 0.23 | 0.26 | 0.42 | 0.19 | 0.16 | 0.24 | 0.10 |
| Lateral entry/gross entry | 0.48 | 0.42 | 0.41 | 0.31 | 0.43 | 0.59 | 0.44 | 0.09 |
| *Average size of entrants in terms of patents with respect to average size of persistent innovators (1979–1981)* | | | | | | | | |
| Gross entrant relative size | 0.35 | 0.39 | 0.40 | 0.51 | 0.32 | 0.35 | 0.39 | 0.09 |
| Lateral entrant relative size | 0.41 | 0.58 | 0.65 | 0.98 | 0.46 | 0.53 | 0.60 | 0.21 |
| New entrant relative size | 0.26 | 0.32 | 0.35 | 0.48 | 0.24 | 0.29 | 0.32 | 0.07 |
| *Average size of entrants in terms of number of employees with respect to average size of persistent innovators (1979–1981)* | | | | | | | | |
| Gross entrant relative size | 0.73 | 0.73 | 1.70 | 0.75 | | | 0.98 | 0.48 |
| Lateral entrant relative size | 0.90 | 4.19 | 4.01 | 1.56 | | | 2.91 | 1.38 |
| New entrant relative size | 0.25 | 0.21 | 0.08 | 0.51 | | | 0.26 | 0.18 |

G, Germany; F, France; I, Italy; J, Japan.

A related major research question regards whether new innovators in a given technological class are *occasional* or *persistent.* Malerba and Orsenigo (1996) have explored whether and for how long new innovators continue to patent after entry, and whether they tend to increase or decrease their technological activity over time. A large proportion of new innovators is composed of occasional innovators. Data show that a large proportion of the new innovators ceases to innovate soon after entry and that survival decreases in the latest entry cohorts. As a result of the processes of entry and exit, the age distribution of innovators is strongly skewed towards the youngest and the oldest cohorts.[8] Data concerning the patent shares of firms that survived after entry confirm these results. The patent share of each entry cohort declines over time in each period and in each country. Moreover, each group of entrants is responsible for its largest share of patents in the period in which

[8] On average, in the period 1989–1991 the 1978–1982 cohort was 16.6% of total innovators, the 1983–1985 accounted for 11.3%, the 1986–1988 cohort for 13.7% and the 1989–1991 for 58.3% of total innovators.

TABLE 10 Technological exit in 1987–1991 with respect to firms patenting in this period

| | G | F | UK | I | USA | J | Av | SD |
|---|---|---|---|---|---|---|---|---|
| *Technological exit: share of firms* | | | | | | | | |
| Gross exit rate/total innovators | 0.62 | 0.70 | 0.74 | 0.67 | 0.68 | 0.53 | 0.65 | 0.07 |
| Lateral exit rate/total innovators | 0.28 | 0.25 | 0.23 | 0.17 | 0.27 | 0.28 | 0.25 | 0.04 |
| Real exit rate/total innovators | 0.34 | 0.45 | 0.50 | 0.50 | 0.41 | 0.24 | 0.41 | 0.10 |
| Lateral exit/gross exit | 0.45 | 0.36 | 0.32 | 0.26 | 0.40 | 0.55 | 0.39 | 0.40 |
| *Technological exit: share of patents* | | | | | | | | |
| Gross exit rate/total innovators | 0.27 | 0.46 | 0.47 | 0.49 | 0.34 | 0.26 | 0.38 | 0.10 |
| Lateral exit rate/total innovators | 0.12 | 0.18 | 0.16 | 0.13 | 0.15 | 0.14 | 0.15 | 0.02 |
| Real exit rate/total innovators | 0.15 | 0.28 | 0.31 | 0.36 | 0.19 | 0.12 | 0.26 | 0.09 |
| Lateral exit/gross exit | 0.46 | 0.40 | 0.36 | 0.28 | 0.45 | 0.56 | 0.42 | 0.10 |
| *Average size of exiters in terms of patents with respect to average size of persistent innovators (1978–1991)* | | | | | | | | |
| Gross exiter relative size | 0.24 | 0.38 | 0.34 | 0.44 | 0.27 | 0.32 | 0.33 | 0.07 |
| Lateral exiter relative size | 0.39 | 0.66 | 0.66 | 0.64 | 0.51 | 0.40 | 0.55 | 0.13 |
| Real exiter relative size | 0.33 | 0.47 | 0.43 | 0.52 | 0.33 | 0.39 | 0.41 | 0.08 |
| *Average size of exiters in terms of number of employees with respect to average size of persistent innovators (1978–1991)* | | | | | | | | |
| Gross exiter relative size | 0.83 | 1.29 | 1.33 | 0.73 | | | 1.04 | 0.31 |
| Lateral exiter relative size | 1.76 | 8.08 | 2.22 | 1.66 | | | 3.43 | 3.11 |
| Real exiter relative size | 0.07 | 0.12 | 0.17 | 0.50 | | | 0.21 | 0.19 |

G, Germany; F, France; I, Italy; J, Japan.

it is first observed.[9] However, the patent share of the 1978–1982 cohort (i.e. firms who were already present in the first period) remains the largest one in each subsequent period. Thus, the age distribution of patent shares in each period is highly skewed, with the oldest and youngest cohorts holding a far larger share of patents than the intermediate classes.[10] The decline in market share of each cohort as the cohort ages is the result of two conflicting forces: the change in the size (in terms of patents) of surviving members of the cohort and the exit of firms from the cohort. The 'older' firms are indeed larger in terms of patents than the younger ones.[11]

[9] The patent share of each cohort of entrants in the first period after entry declines over time (from an average of 49.7% for the 1983–1986 cohort to 40.6% for the 1986–1988 cohort to 34.2% for the 1988–1991 cohort), as the total population of firms increases. Please note that the first cohort (1978–1982) may include also 'persistent' innovators technologically active before 1978, due to the fact the EPO database starts from 1978.

[10] On average, in the period 1989–1991, the 1978–1982 cohort was responsible for 35.9% of total patents in that period, the 1983–1985 and 1986–1988 cohorts both 14.4% and the youngest cohort (1989-91) 34.2%.

[11] Thus, in the period 1989–1991 the average size in terms of patents of the firms in the 1978–1982 cohort was 2.3 times with respect to all innovators, against 1.2 for the 1983–1983 cohort, 0.9 for the 1986–1988 cohort and 0.58 for the 1989–1991 cohort.

In terms of patents, however, occasional innovators do not represent a large proportion of the total number of patents at any give time: thus *persistent innovators* represent an important contribution to total patenting activities in any period (see Tables 9 and 10). This is a clear indication of the presence of cumulativeness in technological knowledge and the process of accruing technological capabilities and competitive advantages by those firms that are able to survive (for a more detailed discussion on this last issue see Cefis, 1996; Geroski *et al.*, 1997).

These patterns of technological entry and exit show substantial diversity across technological classes. Two different types of technological classes emerge.

- One group is composed of *turbulent classes*: high gross entry and exit with most of the entry generated by totally new innovators and most of the exit by firms which stop patenting.
- A second group is composed of *stable classes*: low gross entry and exit, largely associated with processes of technological diversification of firms. In these technological classes, lateral entrants tend to be relatively big (and net entrants small). Conversely exiters (especially net exiters) tend to be smaller innovators.

Note that the entry variables and the exit variables are systematically related to each other within any one technological class. In particular, all the indicators measuring the importance of innovative natality are positively correlated with each other and with the corresponding indicators of mortality: natality and mortality occur simultaneously in each technological class. Moreover, gross entry and exit are negatively correlated with lateral entry and exit. That is to say, technological classes characterized by high turbulence show simultaneously and consistently a lower relative role of lateral entry and exit.

Again, similarly for what has been found for Schumpeter Mark I and Schumpeter Mark II classes, it is possible to claim that the sectoral patterns of innovative entry and exit are remarkably similar across countries. In most countries turbulent and stable technological classes tend to be the same: 21 technological classes are consistently stable and 12 classes tend to be consistently turbulent. Sixteen remaining classes show more variation across countries or do not fit neatly into these two categories.

- The stable group comprises most of the chemical and electronic technologies, vehicles and aircraft.

- The turbulent group includes mechanical technologies, traditional technologies and agriculture.

## 4.2 The Spatial Dimension of Schumpeterian Patterns of Innovative Activities

Using the EPO database, Breschi (1995) has found a remarkable relationship between patterns of innovation and the spatial organization of innovative activities. In general, innovative activities are characterized by high degrees of geographical concentration and of stability in the (national ranking) of innovative regions. However, spatial patterns at the regional level differ systematically across technologies and are closely related to the type of innovative activity. It is possible to identify two broad patterns.

- A *Schumpeter Mark I type of sectoral and spatial pattern* of technological activities, characterized by a large diffusion of innovative activities both across firms and regions, low stability and high entry rates both at the sectoral and the spatial levels. This includes most of the traditional sectors.
- A *Schumpeter Mark II type of sectoral and spatial pattern* of technological activities, characterized by high degrees of sectoral and spatial concentration, high stability in the ranking of innovative regions within a country and low rates of regional as well as of technological natality. In such technologies, innovative activities take place among a stable and very restricted number of locations and firms. This includes most of the chemical and electronic technologies. This evidence broadly confirms the spatial concentration of innovative activity highlighted by Patel and Pavitt (1996) and Cantwell and Fai (1996).

It should be expected that technological regimes have an impact on the spatial distribution of innovators examined before. The following points attempt to summarize the processes at work (Breschi and Malerba, 1996). *Ceteris paribus*, it is expected that high opportunity, appropriability and (firms') cumulativeness conditions are likely to result in high geographical concentration of innovators within each country. In such circumstances, the geographical distribution of innovators closely follows, and is highly and positively correlated with, sectoral concentration. Conversely, one would expect low opportunity, appropriability and (firms') cumulativeness conditions to be associated with a relatively greater geographical dispersion of innovators.

One may conjecture that the *sources* of innovative opportunities strongly affect *where* such opportunities are available and effectively transmitted to firms, therefore shaping the spatial location of innovators. More particularly, in those sectors in which the sources of opportunities are strongly related to R&D activities, universities and public research institutions, one may expect a noticeable concentration of innovators within a few regions, especially metropolitan areas. The availability of qualified human capital, the location of universities and firms' headquarters, and, more generally, the existence of a dense network of interactions drives the *spatial agglomeration* of innovative activities. On the other hand, where suppliers and users represent fundamental sources of new knowledge, the spatial clustering of innovators may arise because *geographical proximity* plays a crucial role in facilitating the establishment of stable and durable relationships among agents, upon which the effective transfer of knowledge is based.

Conversely, one should expect that the *nature* of the relevant knowledge base and the related *means of knowledge transmission* crucially affects how firms can effectively get access to innovative opportunities and knowledge externalities, thus contributing to determine the geographical location of innovators within a country. It may be argued that the more the relevant knowledge base underpinning innovative activities is tacit, complex and part of a larger system, the more geographically concentrated the population of innovators will be. Under such circumstances, in fact, the available 'transport' mechanisms of knowledge are informal. Therefore the spatial proximity among agents may be of paramount importance in facilitating the transmission of knowledge, both within and across different organizations. On the other hand, the more the relevant knowledge base is codifiable, simple and independent, the lower the friction associated with the geographical distance and therefore the lower the geographical concentration of innovators. (Hagerstrand, 1967; Feldman, 1994).

Finally, the effects of technological cumulativeness on the geographical distribution of innovators may differ depending on what is the *relevant dimension of cumulativeness,* as has been discussed previously.

If cumulativeness at the firm level is high (therefore indicating high degrees of appropriability), then one would expect quite high levels of sectoral and consequently geographical concentration of innovators. Selection here takes place on firms located in different regions.

On the other hand, if cumulativeness at the sectoral level is high (therefore indicating the existence of widespread knowledge externalities), the effects on the geographical localisation of innovators crucially depend on the nature of such knowledge externalities and on the available means of knowledge communication. The more knowledge is tacit, complex and systemic, the more likely that geographical proximity plays a role in capturing the benefits of spillovers, thus pushing towards the spatial clustering of innovative activities. Conversely, the more knowledge is standardized, relatively simple and independent (therefore quite easily transferable over long distances), the less spatial proximity is helpful or even necessary in order to get access to the relevant knowledge.

Finally, if cumulativeness at the local level is high (therefore indicating the importance of the local externalities and innovative capabilities accumulated by local firms and institutions), one may expect to record high levels of spatial concentration of innovators within a restricted number of areas. In this case, the selection process does not take place at the firm level. Rather it occurs among regions.

Summing up the previous discussion, it is possible to identify some dimensions of the technological regime that may affect the degree of geographical concentration of innovators.

- *Innovators are geographically concentrated* when high opportunity, appropriability and firms' cumulativeness conditions (in this case spatial concentration overlaps with sectoral concentration) are high, or when a relevant source of scientific and technological knowledge is present in a specific location, or when the knowledge base is characterized by tacitness, complexity and systemic features.
- Conversely, *innovators are geographically dispersed* in case of low opportunity, appropriability and firms' cumulativeness conditions, or a knowledge base which is relatively simple and codified.

## 4.3 Sectoral Innovation Systems

One could expand the notion of Schumpeterian patterns of innovation by also including processes of co-operation and interaction among firms and of utilization and diffusion of new technologies. In this respect Breschi and Malerba (1996) have proposed the concept of the *sectoral innovation system.* A sectoral innovation system can be defined as that group of firms active in developing and making a sector's artefacts and in generating and utilizing a sector's technologies—activities that may be accomplished in two ways: through processes of interaction and co-operation in artefact-technology development, and through processes of competition and selection in innovative and market activities.

The concept of sectoral innovation system bears some relationship to the concept of technological systems (Carlsson and Stankiewitz, 1991) and national innovation systems (Nelson, 1992; Lundvall, 1993; Edquist, 1996) because it focuses on the actors and institutions and on their relationships in the innovation and diffusion process. However, while the first one (the technological system) is mainly technology-specific and is related to the specific cluster of firms engaged in the generation and diffusion of new technologies and knowledge, and the second (the national innovation system) is centred on the actors and institutions and their relationships within national boundaries, a sectoral innovation system perspective focuses more on the industry and on processes of competition as well as co-operation and networking. A sectoral system perspective provides the possibility of developing taxonomies and categories which can be linked to those already proposed in the literature on technical change, such as the one by Pavitt (1990). In particular, Breschi and Malerba (1996) discuss four cases quite common in modern economies:

- traditional sectors such as shoes and textiles;
- machinery and the industrial district;
- the auto industry and the local system of component suppliers;
- the computer mainframe industry, software and microelectronics, and Silicon Valley.

They propose to relate some of the dimensions of sectoral systems of innovations to specific features of technological regimes.

In *most traditional sectors*, one could propose that opportunity, appropriability and cumulativeness conditions are rather low. As a consequence, one could expect that these sectors have geographically dispersed innovators with no knowledge-specific spatial boundaries.

In *mechanical industries*, on the other hand, it could be argued that opportunity conditions are of medium level, appropriability is low, cumulativeness is high, while the knowledge base may be characterized by a high degree of tacitness and specificity. As a consequence, one would expect that these industries have many innovators, geographically concentrated with local knowledge boundaries.

In the *auto industry* it could be proposed that cumulativeness is high at the firm level with a system type of knowledge, which is partly tacit. As a consequence, one would expect few innovators, geographically concentrated with local knowledge boundaries involving other firms (suppliers, etc.).

Finally, the information technology industry presents two quite different innovation systems. In the *computer mainframe* industry (prior to the convergence between mainframes and client-servers), it could be argued that high technology opportunities with limited technological variety of potential technological approaches and solutions are coupled with a knowledge base with strong systemic features and high complexity. Therefore, one would expect few innovators to be present in the industry and that these would be geographically concentrated with global knowledge boundaries. However, in the modern microelectronics and software industries one could argue that opportunity conditions are very high with a wide variety of potential technological approaches and solutions, appropriability conditions related to the appropriation of rents from the continuous introduction of stream of innovation are high, and the relevant knowledge base involves a tacit dimension as well a codified one, where modularity and compatibility play a major role. Therefore one would expect specialization as well as 'Silicon Valley' clustering, with many innovators, geographically concentrated with both local and global knowledge boundaries.[12]

## 5. *Conclusions*

The empirical evidence and analyses reviewed so far strongly support the basic notion that sectoral patterns of innovation are a function of some structural characteristics of the technology and, more generally, of some specific features of learning processes. In this paper it was argued that the nature of technological (and organizational) learning, interacting with processes of market selection, defines specific regimes of industrial evolution, which in turn generate empirically observable regularities in the form of archetypical patterns of innovation which we called Schumpeter Mark I and Mark II. In particular it has been proposed that:

- sectoral patterns of innovation while different across sectors are rather invariant across countries for the same sector;
- the type of technological (learning) regimes affect the specific pattern of innovative activities in a sector.

[12] Malerba and Orsenigo (1993) provide a discussion and some evidence based on case studies regarding microelectronics, biotechnology and the computer industry on the relationships between firms' broad innovative strategies and technological regimes. They propose that various technological regimes defined in terms of combinations of opportunity, appropriability and cumulativeness conditions identify general strategic trade-offs, 'viable strategies' and strategic imperatives. In general, they expect that high opportunity, high cumulativeness and low appropriability imply more complex strategic tasks, but also higher degrees of strategic freedom: the number of viable strategies is likely to be larger. High opportunity allows 'exploration strategies', high cumulativeness allows 'exploitation strategies', while low appropriability also allows followers to pursue 'imitation strategies'. Conversely, when technological regimes are characterized by low opportunity conditions, the range of viable innovative strategies becomes narrower.

These findings constitute a promising viewpoint for more general empirical and theoretical analyses on the factors affecting industry dynamics and more broadly on industrial evolution.

At the empirical level, evidence is now becoming available on the role of several dimensions of technological regimes in affecting the regularities observed in the dynamics of industries. For instance, Gort and Klepper (1982) have examined the relationship between concentration, entry, and the flow of information among existing producers and entrants; Acs and Audretsch (1991) and Audrestch (1997) linked sectoral differences in the patterns of entry and exit and in the relationships between size, age, growth and survival to the nature of the relevant technology, defined in terms of accessibility of technological knowledge by firms external to the industry (as opposed to incumbents). Baldwin (1995) indirectly suggested that some broad characteristics of the learning processes of firms bear an important influence in determining market structure and its evolution over time.

At the theoretical level, these findings are consistent with several models of industrial dynamics, starting from Nelson and Winter (1982), who discussed the evolution of innovation and concentration in various contexts characterized by different degrees of opportunity and appropriability conditions, and Winter (1984), who discussed the evolution of entry and concentration in a routinized and an entrepreneurial regime. Both have found a positive relationship between the levels of appropriability and cumulativeness, and high concentration and low entry in an industry. Similar results regarding entrants have been reached by Jovanovic (1982) in a equilibrium perspective. Finally Dosi *et al.* (1995) have related learning regimes, the accumulation of firms' competences, the evolution of market shares, and entry and exit. They have found that in a cumulative learning regime incumbents grow in size and market share, with limited room for entry. The opposite holds for a non-cumulative learning regime.

What are the future directions of research regarding the relationship between technological regimes, innovation and industrial evolution? An obvious one emerging from this paper calls for richer and more detailed empirical evidence on the links between technological regimes, patterns of innovation and industrial dynamics.

At the theoretical level, models should move from reduced-form models to structural ones. These structural models should provide specific parameterizations of variables such as opportunity, appropriability, cumulativeness and knowledge base, and should represent in detail the functional mechanisms linking the regime variables to technological innovation and market selection first and industrial dynamics later. In this effort, the possibility of non-linearities should be examined carefully. Moreover, these models should consider the possibility of feedback from innovation and market selection to technological and learning regimes, thus making the concept of regime more endogenous with respect to innovation and industrial dynamics. In this respect, evolutionary models and approaches linking technological regimes, innovation and industrial dynamics may be able to account for a wide set of stylized facts and identify some robust correspondences between the distinctive features of observable industrial dynamics and some underlying characteristics of the microeconomic processes of learning and market selection.

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