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TECHNOLOGICAL REGIMES AND SCHUMPETERIAN PATTERNS OF INNOVATION*

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This paper proposes that the specific pattern of innovative activities in an industry can be explained as the outcome of different *technological* (learning) *regimes*. A technological regime is defined by the particular combination of technological opportunities, appropriability of innovations, cumulativeness of technical advances and properties of the knowledge base. Building upon the distinction between Schumpeter Mark I and Schumpeter Mark II industries, this paper provides empirical estimates of the relationships between indicators of the Schumpeterian patterns of innovation (concentration of innovative activities, stability in the hierarchy of innovators and importance of new innovators) and indicators of the variables defining technological regimes.

This paper proposes that the specific pattern of innovative activities in an industry can be explained as the outcome of different *technological* (learning) *regimes*. Building on the Schumpeterian tradition, this paper starts from the recognition that there are two main patterns of innovation in industries. The first one is a *creative destruction* pattern where innovations are introduced by firms that did not innovate before: it is called 'widening'. The second one is a *creative accumulation* pattern where innovations are introduced by firms that innovated before: it is called 'deepening'. Whether an industry is characterised by the first or the second pattern is identified by a variable: a Schumpeterian pattern of innovation of the Mark I or Mark II type. A Schumpeter Mark II pattern (deepening) is associated positively to the concentration ratio of the top four patenting firms and to the stability of the hierarchy of innovators, and negatively to the share of patent applications by firms applying for the first time in a certain period. A Schumpeter Mark I pattern (widening) is the opposite. Then the specific pattern of innovation is explained by technological opportunities, appropriability conditions, cumulativeness of knowledge and the relevant knowledge base in an industry. The paper shows that less technological opportunities, better appropriability conditions, more cumulative knowledge and a knowledge base closer to basic science work in the direction of a deepening (or Schumpeter Mark II) pattern. The opposite holds for a widening (or Schumpeter Mark I) pattern.

The paper is organised in the following way. Section 1 briefly discusses the debate on technological change and patterns of innovation in industry, while Section 2 introduces the basic notion of technological regime. Section 3 discusses in an appreciative way the expected theoretical relationships between the variables defining technological regimes and the patterns of innovative activities. Section 4 illustrates the data used in the empirical analysis. In

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Section 5, we test hypotheses suggested by our framework using European Patent Office (EPO) data and survey data on the dimensions of technological regimes recently collected at Merit Institute (The Netherlands). Finally, Section 6 provides some concluding remarks.

1. The Debate on Technological Change and Patterns of Innovation in Industry: An Introduction

A basic difference in the ways innovative activities are structured and organised may be related to a fundamental distinction between *Schumpeter Mark I* and *Schumpeter Mark II* industries.[1] Schumpeter Mark I is characterised by 'creative destruction' with technological ease of entry and a fundamental role played by entrepreneurs and new firms in innovative activities. New entrepreneurs come in an industry with new ideas and innovations, launch new enterprises which challenge established firms and continuously disrupt the current ways of production, organisation and distribution, thus wiping out the quasi-rents associated with previous innovations. Schumpeter Mark II is instead characterised by 'creative accumulation' with the prevalence of large established firms and the presence of relevant barriers to entry to 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, large established firms create relevant barriers to entry to new entrepreneurs and small firms.[2]

The Schumpeterian Mark I and Mark II patterns of innovation have been labelled also, respectively, *widening* and *deepening*. A widening pattern of innovative activities is related to an innovative base which is continuously enlarging 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 contrary, 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, 1994 and 1996).

The empirical verification of these two archetypes has been at the centre of

[1] The labels *Schumpeter Mark I* and *Schumpeter Mark II* have been originally introduced by Nelson and Winter (1982) and Kamien and Schwartz (1982) to characterise synthetically the theoretical models of innovative activities proposed by Schumpeter, respectively, in *The Theory of Economic Development* (1934) and in *Capitalism, Socialism and Democracy* (1942).

[2] During the evolution of an industry, a Schumpeter Mark I organisation may evolve into a Schumpeter Mark II. According to the industry life cycle view, early in the history of an industry, when technology is changing very rapidly, uncertainty is very high and barriers to entry very low, new firms are the major innovators and they 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). In the presence of major technological and market discontinuities, a Schumpeter Mark II organisation may be replaced by a Schumpeter Mark I. In this case, incumbents with monopolistic power are displaced by new firms which are focusing on the new technology or the new demand (Henderson and Clark, 1990; Christensen and Rosenbloom, 1995).

the economics of innovation ever since its inception. The first, and older, tradition framed the issue in terms of what has been termed the 'market structure and innovation' approach (Kamien and Schwartz, 1982). Here, the focus was on testing the relationship between the rate of innovation and firm size, on the one hand, and monopoly power, on the other. It is now widely acknowledged that the results obtained within this framework suffered of, at least, two main limitations. First, they failed to recognise the mutual causation between innovation, market structure and firm size. Rather, these variables are best thought as endogenously co-determined (Dasgupta and Stiglitz, 1980; Nelson and Winter, 1982). Second, starting from the empirical observation that the relevant relationships varied significantly across industries, it was suggested that other factors, mainly linked to the nature of technology, might be important explanatory variables of the sectoral patterns of innovation. (Pavitt, 1984, Pavitt *et al.* 1987). Thus, even the insertion of very rough proxies of opportunity and appropriability conditions significantly improved the performance of econometric exercises performed in an otherwise conventional approach (Levin *et al.* 1985; Cohen and Levin, 1989).

In recent times, two of us have developed these suggestions in a somewhat different perspective. In particular, we explored directly the empirical question of which (if any) of the two Schumpeterian models of innovation can be actually observed in the data, using a wider notion of the Schumpeterian patterns of innovation. Using both U.S. and European patent data, patterns of innovative activities have been analysed on the basis of a set of indicators aimed to capture some of the essential features of the two Schumpeterian models: concentration and asymmetries of innovative activities among firms, size of innovative firms, change over time in the hierarchy of innovative firms, importance of new innovative firms as compared to established ones (Malerba and Orsenigo, 1994 and 1996). Thus, we did not focus on firm size, market structure and rates of innovation, fully recognising the endogenous and dynamic nature of the relationships between these variables. Rather, we concentrated on how innovative activities proceed across technologies. The empirical evidence suggests that patterns of innovative activities systematically differ across technological classes, grouping around two major clusters which closely resemble the Schumpeter Mark I and the Schumpeter Mark II models. Moreover, cross-country comparisons show striking similarities in the patterns of innovation for each specific technological class, thus supporting the hypothesis that technology-related (rather than country-related) factors play a fundamental role in affecting the sectoral organisation of innovative activities.

Important as they are, these results raise the question of what are the basic determinants of the different observed patterns of innovative activities across technologies. This paper proposes that the specific way innovative activities of a technological class are organised can be explained as the outcome of different *technological* (learning) *regimes* implied by the nature of technology. Specifically, we argue that the observed sectoral patterns of innovative activities are related to the nature of the relevant *technological regime*. A technological regime is defined by the specific combination of technological opportunities, appropriability of innovations, cumulativeness of technical advances and the properties of the knowledge base underpinning firms' innovative activities. The notion of technological regime provides a synthetic way of representing some of the most important economic properties of technologies and of the characteristics of the learning processes that are involved in innovative activities. Thus, it identifies some fundamental structural conditions that contribute to define the requisite competencies, the incentives and the dynamic properties of the innovative process.

2. The Dimensions of Technological Regimes

The notion of *technological regime* dates back to the works of Nelson and Winter (1982) and Winter (1984). They built simulation models showing that the technological environment described in terms of opportunity and appropriability conditions has major effects on the intensity of innovation, the degree of industrial concentration and the rate of entry in an industry. In a different perspective, the same variables – especially appropriability conditions – play a fundamental role in game-theoretic models, defining the nature of the game which is to be played (e.g. winner takes all vs. waiting games). At the empirical level, various authors – Gort and Klepper (1982), Cohen and Levin (1989) and Audretsch (1995) among others- have pointed out that, more than firm size or demand, these variables appear as the most relevant factors affecting the dynamics of market structure and innovation.[3] In recent times, Malerba and Orsenigo (1990 and 1993) have further developed this notion.

A technological regime can be broadly defined by the particular combination of four fundamental factors: technological opportunities, appropriability of innovations, cumulativeness of technological advances, properties of the knowledge base.

Technological opportunities reflect the likelihood of innovating for any given amount of money invested in search. High opportunities provide powerful incentives to the undertaking of innovative activities and denote an economic environment that is not functionally constrained by scarcity. In this case, potential innovators may come up with frequent and important technological innovations.[4]

Appropriability of innovations summarises the possibilities of protecting innovations from imitation and of reaping profits from innovative activities. High

[3] The notion of technological regime holds some relationship with the concepts of technological paradigms and trajectories. These latter try to capture the idea that the technologies differ drastically and that their development retains a strong autonomous internal logic (Dosi, 1982 and 1988).

[4] It should be pointed out that opportunity conditions may greatly change in the course of the evolution of industries. In several industries technological opportunities may become eventually depleted, as the literature on industry life-cycle has emphasised (Klepper, 1996). On the other hand, there are industries where opportunities are regenerated and recreated by firms' innovative activities, such as R&D. In this paper, we will examine the effects of opportunity conditions at a given point in time. It is therefore possible that a technological environment characterised by specific opportunity conditions may be related to a specific stage in the development of an industry, which in this paper is going to be considered constant over the whole period examined.

appropriability means the existence of ways to successfully protect innovation from imitation. Low appropriability conditions denote an economic environment characterised by the widespread existence of externalities (Levin *et al.* 1987). The particular regime of appropriability has two different effects on innovative output: an incentive effect and an efficiency effect. High appropriability levels have an incentive effect, which increases the R-D spending by individual firms. On the contrary, high appropriability levels may reduce the possibility that other firms benefit from such technical advances, therefore reducing the positive efficiency effect on technical advances at the sectoral level (Levin and Reiss, 1988).

Cumulativeness of technical advances is related to the fact that today knowledge and innovative activities form the base and the building blocks of tomorrow innovations: an innovation generates a stream of subsequent innovations, which are a gradual improvement on the original one, or creates new knowledge which is used for other innovations in related areas. High levels of cumulativeness are therefore typical of economic environments characterised by continuities in innovative activities and increasing returns. As a consequence, today innovative firms are more likely to innovate in the future in specific technologies and along specific trajectories than non-innovative firms are.[5]

The *properties of the knowledge base* relate to the nature of knowledge underpinning firms' innovative activities. Technological knowledge involves various degrees of specificity, tacitness, complexity and independence and may greatly differ across technologies (Winter, 1987). In this paper, only the *generic vs. specific* dimensions of knowledge base will be examined. In particular, *generic knowledge* refers to knowledge of a very broad nature, while *specific knowledge* refers to knowledge specialised and targeted to specific applications. Generic or focused knowledge may be also related to different types of sciences. *Basic sciences* generate generic knowledge, by providing broad general understanding that may also affect research in applied sciences. On the contrary, *applied sciences* are more focused and respond to problems generated by practical experience. They are closely related to problem solving in applied technologies (Klevorick *et al.* 1995).

3. The Basic Relationships between Technological Regimes and Schumpeterian Patterns of Innovation

In this paper, we are exploring the effects of technological regimes in terms of opportunity, cumulativeness, appropriability conditions and properties of the knowledge base on the sectoral patterns of innovative activities. In particular, three dimensions of Schumpeterian patterns of innovation have been identified here: (i) the rate of concentration of innovative activities among firms

[5] Cumulativeness can actually take place at four different levels: 1. Technological 2. Organisational (i.e. at the laboratory or at the firm level) 3. Market (i.e. the 'success breeds success mechanism') 4. Industry (i.e. through spillovers). In this paper, the term cumulativeness will be used with reference to the first and second dimensions: the *technological-cognitive* level and the *organisational-firm* level.

(*CONC*); (ii) the degree of stability in the hierarchy of innovative firms (*STAB*); (iii) technological entry and exit (*ENTRY*) (i.e. the relevance of new innovators in an industry).

This paper proposes that the specific patterns of innovative activities in a given industry are determined by the prevailing technological regime as measured by the specific values of: technological opportunities (*OPP*), appropriability of innovations (*APP*), cumulativeness of technical advances (*CUM*), and properties of knowledge base related to basic sciences (*KBA*) (generic knowledge) and to applied sciences (*KAP*) (specific knowledge). The relationships between technological regimes and sectoral patterns of innovation can be summarised in the following relationships regarding *ENTRY*, *CONC* and *STAB*.

3.1. *Technological Entry and Exit (ENTRY)*

Ceteris paribus high technological opportunities tend to favour the technological entry of new innovators. In fact, by raising the expected returns of R&D high opportunity conditions increase the incentives to engage in innovative search. Conversely, conditions of low technological opportunities limit innovative entry and restrict the innovative growth of successful established firms. As previous theoretical models (Winter, 1984; Jovanovic, 1982) have shown, higher opportunities provide potential entrants with an ample pool of available scientific and technological knowledge, thus affecting entry in a positive way. *Ceteris paribus* technological entry and exit are high if cumulativeness is low. In this case, in fact, would-be innovators are not at a major disadvantage with respect to incumbent firms, as discussed in Winter (1984). Finally, we expect that a knowledge base of a generic type related to basic sciences will be negatively related to entry, because firms need to have already accumulated absorptive capabilities in order to integrate and use generic knowledge. On the contrary, a knowledge base of a specific type related to applied sciences is going to be positively related with entry, because new innovators may profit from the availability of specialised knowledge (Cohen and Levinthal, 1989).

3.2. *Concentration of Innovative Activities (CONC)*

Ceteris paribus, high technological opportunities allow for the entry of new innovative firms, thereby reducing concentration. The opposite holds for low opportunity conditions. It is worthwhile to note, however, that the impact of technological opportunities on the concentration ratio of innovative activities may depend on the interactions between opportunity, appropriability and cumulativeness conditions. In particular, if high technological opportunities make big technological leaps likely and these advantages are reinforced in subsequent rounds of innovative activity by high appropriability and cumulativeness conditions, concentration of innovative activities will increase, instead of decreasing. Existing theoretical models support both these conjectures. From Nelson and Winter (1982), Jovanovic and Lach (1988), Winter (1984), Iwai (1984*a,b*) and Dosi *et al.* (1995) among others, we expect ambiguous effects of technological opportunities on concentration. On the one hand, high opportunity conditions increase the possibility of widening the population of innovative firms (therefore reducing concentration); on the other hand, as they determine major differences in innovative rates among firms and are coupled with high appropriability and cumulativeness conditions, they may end up increasing concentration.

Ceteris paribus, by limiting the extent of knowledge spillovers and by allowing successful innovators to maintain their innovative advantages high degrees of technological appropriability are expected to result in a relatively higher level of concentration of innovative activities. Conversely, by determining a wider diffusion of the relevant knowledge across firms, low appropriability conditions are more likely to lead to the presence of a large population of innovators. Also theoretical models, such as Nelson and Winter (1982) and Jovanovic and Lach (1988), point to this relationship: higher appropriability of innovations in fact allows greater advantages to innovators and leads to a greater concentration of innovative activities. Similarly, from Winter (1984) we expect that, *ceteris paribus*, the relationship between cumulativeness of technical advances and concentration is positive: higher cumulativeness of technical advances means that existing innovative firms increasingly build upon their existing innovations and capabilities, therefore increasing the concentration of innovative activities.

Regarding the properties of knowledge base, the availability of generic knowledge related to basic sciences can, in principle, allow a variety of different agents to engage in innovative activities. However, the access to the knowledge base and its exploitation often require the presence of absorptive capabilities by existing firms (Cohen and Levinthal, 1989; Rosenberg, 1990) and therefore costly R&D and other learning activities that tend to increase the level of innovative concentration. Conversely, specific knowledge related to applied sciences is more specialised and accessible to firms (both established and new), with a negative effect on the level of innovative concentration.

3.3. *Stability in the Ranking of Innovators (STAB)*

From Winter (1984) and Dosi *et al.* (1995), we may conjecture that the relationship between stability in the ranking of innovative firms and appropriability and cumulativeness conditions is positive: stability is high if appropriability and cumulativeness are high. In this case leading innovators maintain their top positions because they are able to innovate continuously building on their previous innovations (high cumulativeness) and to protect their innovations from imitation (high appropriability). Existing innovators accumulate technological knowledge and capabilities that act as powerful barriers to the entry of new innovators. As opportunity conditions are concerned, in general a negative relationship may be expected; as higher opportunities favour entry and increase the likelihood of innovating, they also tend to disrupt the existing ranking of innovators. As mentioned in the previous paragraph, however, in conjunction with high appropriability and high cumulativeness conditions, the opposite effect may prevail.

3.4. *Technological Regimes and Schumpeterian Patterns of Innovation*

The working of the variables of a technological regime affect the specific sectoral pattern of innovative activities. Table 1 summarises the expected theoretical relationships. In order to keep the discussion at a very simple level, we will concentrate on *Schumpeter Mark I* and *Schumpeter Mark II* patterns of innovation. The relationships to be tested are the following:

(i) *Schumpeter Mark I – Widening* (Large and highly turbulent population of innovators): High technological opportunities, low appropriability and low cumulativeness (at the firm level) conditions and a limited role of generic knowledge lead to low degrees of concentration of innovative activities with a relatively large number of innovators, high rates of entry and high instability in the hierarchy of innovators.

(ii) *Schumpeter Mark II – Deepening* (Concentrated and rather stable population of innovators): Low opportunity conditions, high appropriability and high cumulativeness (at the firm level) conditions and a generic knowledge base lead to high degrees of concentration of innovative activities, low rates of entry and a remarkable stability in the hierarchy of innovators. However, also high opportunity conditions in conjunction with high appropriability conditions may be associated to a Schumpeter Mark II pattern.

4. The Data

In this paper, patent data have been used to construct measures of Schumpeterian patterns of innovative activities. The limitations of patent data are well known. Not all innovations are patented by firms. The value of single patents cannot be assessed unless specific analyses of patent renewals or patent citations are done. Different technologies are differently patentable and firms may have different propensities to patent their innovations. However, patents represent a very homogeneous measure of technological novelty and are available for long time series. They also provide very detailed data at the firm

Table 1

Expected Theoretical Relationships between Patterns of Innovation and Characteristics of Technological Regime

	Pattern of innovation		
	Concentration (*CONC*)	Stability (*STAB*)	Entry and exit (*ENTRY*)
Technological Regime			
Opportunities (*OPP*)	+/−	+/−	+
Appropriability (*APP*)	+	+	−
Cumulativeness (*CUM*)	+	+	−
Generic knowledge (*KBA*)	+		−
Specific knowledge (*KAP*)	−		+

and technological class levels. For our present purposes, they represent therefore a very valuable and unique source of data on innovative activity.[6]

This paper has used the EPO-CESPRI database, which is based on European Patent Office (EPO) data for the period 1978–91.[7] The database refers to patent applications to EPO by firms and institutions from three countries: Italy, Germany and the United Kingdom.[8] For each country, the whole population of patenting firms has been analysed.[9] In total, 15,175 patents and 3,803 firms have been considered for Italy, 108,118 patents and 8,495 firms for Germany, and 35,175 patents and 6,055 firms for the United Kingdom.

Using the EPO-CESPRI database, four measures of Schumpeterian patterns of innovative activities are considered in this paper: *ENTRY*, *STABILITY*, *C4* and *SCHUMP*.[10] For each country and each technological class, the four measures are defined as follows:

(1) *ENTRY* is the percentage share of patent applications by firms applying for the first time in a given technological class in the period 1986–91 over the total patent applications in the same period. It must be pointed out that this indicator refers to new innovators. In other terms, it measures innovative birth and not to entrepreneurial birth: a new innovator may in fact be a firm having been active for quite a long time.[11] Moreover, *ENTRY* refers to gross entry (i.e.

[6] For a recent discussion on the use of patents as economic indicator see Griliches (1990).

[7] Center for Research on Internationalisation (CESPRI) (Bocconi University, Milan).

[8] The EPO-CESPRI database also contains data for France, Japan and United States. However, these countries have not been considered in the present analysis since we lacked consistent data on industry-specific technological conditions (i.e. technological regimes) for them. In a related paper, Malerba and Orsenigo (1996) have also analysed the population of patenting firms for France, Japan and the United States.

[9] The EPO-CESPRI database has been assembled at the level of individual firms and institutions. Hereafter, for sake of brevity, we will use the term 'firms' instead of 'firms and institutions'. Firms that are part of business groups have been treated in the present analysis as individual companies. In the case of co-patenting, each co-patentee has been credited the patent. Individual inventors have been excluded from the dataset. Since individual inventors are mostly self-employed or owners of small independent firms, their exclusion from the dataset could underestimate the contribution of smaller companies to the innovative activities. However, the share of total patent applications held by private individuals in the dataset is rather small: 2.5% in Germany, 2.1% in United Kingdom and 2.9% in Italy. Patent data have been aggregated into 48 main technological classes and one residual class. These classes have been created grouping the original 12-digits subgroups of the International Patent Classification (IPC) according to the specific application of patents (WIPO, 1994). Finally, one must note that since the EPO is located in Germany, German firms are over-represented in the sample. However, because the focus in this paper is not on the absolute technological performance of countries, but on the structure of innovative activity at the industry level, we think that this does not create too serious a distortion in our results.

[10] The first two measures aim to shed light on the degree of stability and 'creative accumulation' or dynamism and 'creative destruction' in the organisation of innovative activity. The *C4* ratio has been instead conventionally used in more traditional discussions of the Schumpeterian hypotheses in order to measure the extent to which innovative activities are concentrated in few firms or are evenly distributed across a large number of firms. All the indicators of Schumpeterian patterns of innovative activity used in this paper have been drawn from Malerba and Orsenigo (1996). The interested reader may refer to that contribution for a more comprehensive discussion of results and tables.

[11] Please note that our data do not allow us to identify new firms entering into markets by innovating. In other terms, we are unable to distinguish the subset of new firms within the set of all new innovators (i.e. *ENTRY*). Having this kind of information would be, of course, extremely valuable since it would permit us to link the Schumpeterian approach to the industrial organisation literature on the persistence of monopoly (Gilbert and Newbery, 1982). On this point, we gratefully acknowledge the comments of an anonymous referee.

exit rates have not been considered in this analysis) into a specific technology.[12]

(2) *STABILITY* is measured by the Spearman rank correlation coefficient between the hierarchies of firms patenting in the 1978–85 period and firms patenting in the 1986–91 period.

(3) *C4* represents the concentration ratio of the top four patenting firms in a given technological class in the period 1978–91.

(4) *SCHUMP* provides a synthetic indicator of the Schumpeterian patterns of innovation by measuring the extent to which a given technological class belongs to either Schumpeterian models of innovative activity. To this purpose, we performed principal component analysis using *ENTRY*, *STABILITY* and *C4*.[13] The analysis identifies in all three countries one dominant factor that captures a substantial fraction of the variance: 83% in Germany, 81% in United Kingdom and 68% in Italy. In all countries, this factor loads positively on *STABILITY* and *C4* and negatively on *ENTRY*.[14] For each country and each technological class, the variable *SCHUMP* is defined by the factor score coefficient resulting from principal component analysis. For any given technological class, a positive and higher value of *SCHUMP* indicates therefore that the structural features of the class are more in accordance with a Schumpeter Mark II model of innovative activity (deepening pattern). Conversely, a negative and lower value of *SCHUMP* indicates that the structural features of the class are more in accordance with a Schumpeter Mark I model of innovative activity (widening pattern).

Data on industry-specific technological conditions (i.e. technological regime) were drawn from the recent PACE (Policy, Appropriability and Competitiveness for European Enterprises) questionnaire survey co-ordinated by *MERIT* Institute (The Netherlands). The questionnaire was addressed to 713 R&D executives from the European union's largest manufacturing firms with the aim of obtaining their opinions on 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 business unit, as defined by four-digit ISIC (1989, Rev. 3) sectors, of the R&D managers who received the questionnaire. On the whole, the 713 sample business units were operated by 414 firms in 101 manufacturing sectors. The

[12] Gross entry in a given technological class can be decomposed into two parts: lateral entry and new entry. The former refers to those firms patenting for the first time in a technological class which have already patented in other technological classes. The latter refers instead to those firms which innovate for the first time in a given technological class and which have never patented before in any other technological class (for a more in depth discussion, see Malerba and Orsenigo, 1999).

[13] Please note that the Schumpeterian patterns of innovation are defined by specific combinations of the three variables examined here, and not by each variable individually considered. Principal component analysis is therefore appropriate to capture the combined effects of the three variables defining the Schumpeterian patterns of innovation.

[14] Specifically, the correlation (factor loadings) between the principal component and *STABILITY*, *C4* and *ENTRY* is respectively: 0.88, 0.71, −0.95 for Germany, 0.92, 0.85, −0.94 for United Kingdom and 0.91, 0.76, −0.81 for Italy.

number of business units included in the survey however drops to 555 when analysis is restricted to Italy, United Kingdom and Germany. These units correspond to 96 four-digit ISIC sectors.[15]

Using PACE questionnaire data, four sets of indicators have been built for technological opportunity, appropriability and cumulativeness conditions and for the nature of the knowledge base:

(1) The first indicator refers to the sources of technological opportunities. The questionnaire asked respondents to report the importance (on a five-point Likert scale[16]) to the innovative activities of their units of technical knowledge obtained from various external sources. Here, we consider five such sources: suppliers of raw material, components and equipment, independent users, universities and public research laboratories, joint-ventures, and affiliate firms. For each individual respondent, the variable *OPPORTUNITY* is the sum of scores received by the five external sources of technological opportunities.

(2) Appropriability conditions are measured here with responses (on a five-point Likert scale) 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* for each individual respondent is the sum of scores received by each of these two mechanisms for both process and product innovations.

(3) In order to measure cumulativeness conditions, we refer to a question related to the frequency of product innovations. Questionnaire respondents were asked to evaluate (on a five-point Likert scale) the importance of frequent technological improvements in making their unit's product innovations difficult or commercially unprofitable to imitate. The score received by this question – the variable *CUMULAT* – can therefore be assumed as a quite satisfactory proxy of the degree with which technical advances in a given industry takes place in a 'cumulative' way.[17]

(4) Finally, the nature of the relevant knowledge base is captured here by the answers to questions concerning the relevance of science. Questionnaire respondents were asked to rate (on a five-point Likert scale) the importance to the progress of their unit's technological base of publicly funded research in

[15] The PACE questionnaire data have certain limitations. The most relevant one is that the sample units are drawn almost entirely from the 500 largest European firms, as measured by domestic sales of manufactured products. This limitation is partly mitigated by the fact that the sample comprises business units of all sizes. Moreover, the use of survey responses in this paper is chiefly aimed at capturing the relevant technological conditions prevailing in each sector as perceived by R&D managers involved in innovative activities. From such perspective, the PACE questionnaire data represent an extremely valuable source of information since they allow us to derive measures for technological opportunity, appropriability and cumulativeness conditions and for the nature of the relevant knowledge base across manufacturing sectors. For a fuller account of the methodology and the results of the PACE study see Arundel *et al.* (1995).

[16] For all questions of the PACE questionnaire used in this paper the five-point Likert scale ranges from 1 = not at all important to 5 = extremely important.

[17] It must be noted that the frequency of technological improvements may come from different additional knowledge sources instead of being caused by deepening a given knowledge source. From this perspective, the variable used in this paper to measure cumulativeness conditions must be considered a very rough indicator of the phenomenon under investigation.

ten fields of basic and applied science over the past ten years. *BASSCIENCE* represents for each individual respondent the sum of scores received by four fields of basic science: biology, chemistry, physics, and mathematics. *APPSCIENCE* represents instead the sum of scores received by six fields of applied science: materials science, medical and health, chemical engineering, electrical engineering, computing science and mechanical engineering. The two measures of the knowledge base adopted here do not differ in terms of the codified or codifiable nature of the underlying knowledge, both being related to publicly available research. Rather, they attempt at grasping different dimensions of such knowledge, the former being related to the notion of *generic knowledge*, while the latter being more directly related to the concept of process and product *specific knowledge*.[18]

After merging the EPO and the PACE datasets, the sample of firms falls to 437 business units representing 69 four-digit ISIC manufacturing sectors and 26 technological classes.[19] Using the value of the variable *SCHUMP* to discriminate between alternative Schumpeterian models of innovative activity, our sample comprises 9 technological classes which are consistently (i.e. in all the three countries) in the Schumpeter Mark I camp: mining, medical preparations, natural, artificial fibres and paper, industrial machinery, railways and ships, civil engineering, mechanical and electrical technologies, household electrical appliances, measurement and control instruments. On the other hand, there are 9 technological classes which are consistently in the Schumpeter Mark II camp: gas, hydrocarbons and oil, organic chemicals, macromolecular compounds, miscellaneous chemical compounds, agricultural chemicals, vehicles, engines, turbines and pumps, electronic components, consumer electronics. The remaining 8 technological classes present different behaviours in specific countries.[20] Table 2 reports for each of the 18 technological classes unambiguously belonging to one of the two Schumpeterian patterns of innovation the mean value and the standard deviation of the four indicators considered here. Moreover, it also reports summary statistics calculated with reference to all 26 technological classes included in our sample.

5. The Empirical Model

Given the absence of a specific structural model, the dependence of Schumpeterian patterns of innovative activities on measured industry characteristics has

[18] For a taxonomy and a discussion of the various dimensions of the knowledge base see Winter (1987). For a similar interpretation of the distinction between basic and applied sciences see Cohen and Levinthal (1989).

[19] The 26 technological classes included in our analysis account for 66.8% of the overall patenting activity in the period 1978–91 in Italy, 67.7% in United Kingdom, and 68.5% in Germany. However, in the case of Italy, the PACE questionnaire does not comprise any business unit for 5 of these 26 technological classes.

[20] Specifically, these classes are: food and tobacco (Schumpeter Mark I only in Germany), new materials and metallurgy (Schumpeter Mark II only in United Kingdom), adhesives, coatings and resins, drugs and aircraft (Schumpeter Mark I only in Italy), computers (Schumpeter Mark I only in United Kingdom) and electrical devices and systems (Schumpeter Mark II only in Germany).

Table 2

*Indicators of Schumpeterian Patterns of Innovation Mean Values (Standard Deviations) by Technological Class**

Classes	*C4*	*STABILITY*	*ENTRY*	*SCHUMP*
Schumpeter Mark I				
Civil Engineering	9.87	−0.45	63.83	−1.09
	(4.52)	(0.21)	(17.44)	(0.22)
Mechanical, Electrical Technologies	17.47	−0.49	59.57	−0.92
	(6.12)	(0.23)	(18.40)	(0.13)
Mining†	19.81	−0.32	59.35	−0.87
	(4.91)	(0.16)	(4.09)	(0.29)
Railways and Ships	26.47	−0.44	63.40	−0.81
	(9.23)	(0.17)	(16.36)	(0.57)
Natural, Artificial Fibres, Paper†	22.35	−0.29	58.15	−0.73
	(2.62)	(0.16)	(14.50)	(0.02)
Household Electrical Appliances	21.17	−0.38	58.17	−0.63
	(4.80)	(0.17)	(21.53)	(0.43)
Industrial Machinery	13.20	−0.35	47.20	−0.47
	(3.90)	(0.21)	(16.58)	(0.13)
Medical Preparations†	25.70	−0.28	43.10	−0.34
	(7.35)	(0.13)	(10.75)	(0.04)
Measurement and Control Instruments	20.27	−0.31	43.50	−0.23
	(8.23)	(0.19)	(18.70)	(0.33)
Schumpeter Mark II				
Organic Chemicals	49.40	0.17	11.00	1.83
	(22.00)	(0.16)	(8.25)	(0.56)
Miscellaneous Chemical Compounds†	85.11	−0.08	10.78	1.77
	(5.62)	(0.12)	(2.52)	(0.95)
Macromolecular Compounds	61.07	−0.07	19.13	1.38
	(11.27)	(0.15)	(14.09)	(0.21)
Electronic Components	44.33	−0.10	27.17	0.92
	(11.16)	(0.22)	(9.70)	(0.45)
Gas, Hydrocarbons, Oil	44.68	−0.16	33.87	0.71
	(12.21)	(0.21)	(22.13)	(0.37)
Agricultural chemicals†	58.01	−0.22	26.56	0.69
	(16.15)	(0.03)	(7.88)	(0.03)
Consumer Electronics	41.47	−0.26	30.67	0.48
	(9.80)	(0.17)	(14.96)	(0.35)
Engines, Turbines and Pumps	38.43	−0.27	32.93	0.40
	(0.42)	(0.19)	(15.41)	(0.17)
Vehicles	33.53	−0.26	31.37	0.35
	(7.43)	(0.19)	(14.48)	(0.02)
Summary Statistics‡				
Mean	32.40	−0.17	38.44	
Std. Dev.	17.35	0.20	19.60	
Min	2.25	−0.68	6.82	
Max	90.91	0.35	89.09	

Source: EPO-CESPRI (Centre for Research on Internationalisation-Bocconi University) database.
Notes: * the table reports mean values and standard deviations only for the 18 classes which belong unambiguously to one of the two Schumpeterian patterns of innovation;
† Italy is not included because of lack of Italian business units in the PACE questionnaire;
‡ summary statistics are calculated with reference to all 26 technological classes included in our sample.

been assumed here to be linear. Taking the four measures of Schumpeterian patterns of innovation as dependent variables, we begin from estimating the effects of technological regime variables, as measured by individual responses to survey questions.[21] In addition to that, after having categorised our dependent variable, we estimate a logit model to assess the contribution of our explanatory variables to the probability of observing a Schumpeter Mark I or a Schumpeter Mark II model of innovative activity.

We also control for differences across countries in the relationship between Schumpeterian patterns of innovation and technological regimes using fixed country effects. Country dummy variables are used here to capture all those country-specific effects, like the role of public procurement, the interaction among users and producers, and so forth, which in appreciative theories have been categorised under the notion of 'national system of innovation' and which may affect the patterns of innovative activities in industries differently across nations (Nelson, 1993).[22]

An econometric issue that has to be dealt with refers to the possible collinearity among explanatory variables, which may result in less statistically significant coefficient estimates than expected. Although we could not reject the presence of collinearity among our independent variables, the problem was most severe for collinearity between *CUMULAT* and *APPROPRIABILITY*.[23] While the relationship between appropriability and cumulativeness conditions can, to some extent, be justified from a theoretical perspective – a higher cumulativeness resulting in a greater appropriability (Nelson and Winter, 1982; Jovanovic, 1982) – the inclusion of both variables in the specification can make it difficult to isolate their separate effects. As a consequence, in order to detect what impact the variables have within the model, we also estimated separate regressions for *CUMULAT* and *APPROPRIABILITY*.

In the present analysis, we side-step several statistical issues that emerge from the use of Likert-scale survey responses as independent variables in regressions. Among these issues, the most relevant one is related to the use of responses along a semantic continuum as if they were interval data. Here, we follow other authors (Cohen *et al.* 1987; Levin *et al.* 1985; Levin, 1988) and assume that, in the absence of alternative measures of technological opportunity, appropriability and cumulativeness conditions, and of the nature of the knowledge

[21] The use of individual responses, instead of industry means, while questionable, is justified here to reduce the influence of individual measurement errors in questionnaire responses. In fact, since there are only few respondents in several sectors, the use of average scores (instead of individual responses) could magnify the importance of outlying responses.

[22] In a previous paper, Malerba and Orsenigo (1996) have shown that important differences across countries, for example in the level of concentration or in the role of new innovative firms, may still persist as a result of the specific features of national systems of innovation and the specific histories of industries and firms.

[23] Although the sample correlation coefficient between *CUMULAT* and *APPROPRIABILITY* is only 0.30, the sum of squared errors from auxiliary regression of *CUMULAT* on the other explanatory variables is low relative to the error variance in the model, thus resulting in larger sampling variance of the associated least square parameter estimator.

base, such treatment is appropriate.[24] Furthermore, as Levin *et al.* (1987, p. 785) point out, 'although the use of semantic scales to assess, for example, the effectiveness of alternative means of appropriation introduces considerable measurement error, more readily quantifiable proxies would not serve as well'.

5.1. *Regressions Results*

As we argued above, our main interest in this paper is to estimate the impact of technological regime variables on Schumpeterian patterns of innovation as defined by the specific combination of entry, stability and concentration. More specifically, our aim here is to assess the effect of our independent variables on two alternative models of organisation of innovative activities across technological classes: a *widening* pattern, which corresponds to high rates of innovative entry, low stability in the ranking of innovative firms and low concentration of innovative activities (Schumpeter Mark I) and a *deepening* pattern, which corresponds instead to low rates of innovative entry, high stability in the ranking of innovators and high concentration of innovative activities (Schumpeter Mark II). In order to test such effects, our benchmark specification is:

$$\begin{aligned} SCHUMP = \alpha_0 + \beta_0 APPSCIENCE + \beta_1 BASSCIENCE \\ + \beta_2 APPROPRIABILITY\ (CUMULAT) \\ + \beta_3 OPPORTUNITY + \beta_4 DItaly + \beta_5 DUKingdom + \varepsilon \end{aligned} \quad (1)$$

As said above, the variable *SCHUMP* summarises the relationships among individual indicators and it can be assumed as measuring the extent to which a given technological class belongs to either Schumpeterian models of innovation. More precisely, for any given technological class, a positive and higher value of *SCHUMP* indicates that the structural features of the class are more in accordance with a Schumpeter Mark II model of innovative activity (deepening pattern). Conversely, a negative and lower value of *SCHUMP* indicates that the structural features of the class are more in accordance with a Schumpeter Mark I model of innovative activity (widening pattern).

The results of OLS estimates of (1) are reported in Table 3. To explore further the impact of technological regimes on Schumpeterian patterns of innovation, we also report logit estimates of (1) obtained by categorising our dependent variable. In particular, we defined our dependent variable to equal one if in a given technological class the value of *SCHUMP* was positive (i.e. if

[24] Additional concerns may derive from other potential sources of measurement errors. Particularly, individual respondents may differ in their use of Likert-scale, thus introducing possible biases through differences in subjective attitudes. In this respect, we assume here that this effect is reasonably averaged out since for most industries there is a sufficiently large number of responses and, more fundamentally, the cultural background of respondents is conceivably quite homogenous. Moreover, the use of individual responses instead of industry means mitigates at least one possible form of measurement errors, which derives from the different number of survey responses per industry thus improving the precision of estimates.

Table 3

The Effects of Technological Regime and Market Structure on SCHUMP

Independent Variables	(1) OLS†	(2) OLS†	(3) Logit‡	(4) Logit‡
Intercept	0.149	0.509***	0.725	1.670
	(0.768)	(2.813)	(1.218)	(2.972)
APPSCIENCE	−0.035***	−0.034***	−0.058**	−0.050**
	(−4.510)	(−4.367)	(−2.441)	(−2.153)
BASSCIENCE	0.040***	0.055***	0.080**	0.109***
	(3.215)	(4.432)	(1.995)	(2.891)
APPROPRIABILITY	0.058***		0.153***	
	(5.703)		(4.899)	
CUMULAT		0.095***		0.181**
		(3.243)		(2.183)
OPPORTUNITY	−0.031***	−0.027**	−0.119***	−0.099**
	(−2.648)	(−2.229)	(−2.824)	(−2.461)
DItaly	−0.017	−0.049	−0.346	−0.420
	(−0.195)	(−0.519)	(−1.112)	(−1.377)
DUKingdom	0.093	0.074	−0.090	−0.139
	(1.106)	(0.860)	(−0.346)	(−0.555)
Adj. R^2	0.120	0.072		
	F(6,430)	F(6,430)		
	10.88***	6.69***	$\chi^2(6)$	$\chi^2(6)$
			39.19***	19.14***
n	437	437	437	437

Notes: † Heteroskedasticity-robust t values in parentheses;
‡ Heteroskedasticity-robust asymptotic t values in parentheses.
* Significant at 0.10 level.
** Significant at 0.05 level.
*** Significant at 0.01 level.

the class belongs to the Schumpeter Mark II camp) and zero otherwise (i.e. if the class belongs to the Schumpeter Mark I camp).

Finally, by substituting *SCHUMP* by *ENTRY*, *STABILITY* and *C4* in (1), we can also get estimates of the effects of technological regime variables on individual dimensions of Schumpeterian patterns of innovation. The results of OLS estimates for *ENTRY*, *STABILITY* and *C4* are reported in Table 4.

For each variable defining technological regimes, the main results that emerge from the analysis are the following.

5.1.1. *Technological opportunity*

The richness of technological opportunities is captured here by the variable *OPPORTUNITY*. The coefficient of *OPPORTUNITY* is statistically significant in regressions for *SCHUMP* and it has a negative sign. This result therefore suggests that an increasing importance of external sources of technical knowledge is positively associated with 'widening' patterns of innovation (Schumpeter Mark I). More particularly, higher technological opportunities provide incentives to the entry of new innovative firms thus changing the hierarchy of innovators and thereby reducing the level of concentration. Regressions for

Table 4

The Effects of Technological Regime and Market Structure on ENTRY, STABILITY and C4 (OLS)

Independent variables/	(1)	(2)	(3)	(4)	(5)	(6)
	ENTRY		*STABILITY*		*C4*	
Intercept	27.070***	20.084***	−0.040	0.018	26.427***	32.653***
	(7.419)	(5.852)	(−1.009)	(0.493)	(5.537)	(7.208)
APPSCIENCE	0.557***	0.535***	−0.009***	−0.008***	−0.411**	−0.408**
	(3.928)	(3.732)	(−5.534)	(−5.445)	(−2.050)	(−2.013)
BASSCIENCE	−0.657***	−0.912***	0.011***	0.012***	0.506	0.807**
	(−2.993)	(−4.279)	(4.276)	(5.032)	(1.568)	(2.519)
APPROPRIABILITY	−1.089***		0.007***		1.197***	
	(−5.789)		(3.631)		(4.454)	
CUMULAT		−1.683***		0.007		2.448***
		(−2.993)		(1.149)		(3.506)
OPPORTUNITY	0.779***	0.710***	−0.006**	−0.005*	−0.337	−0.284
	(3.506)	(3.108)	(−2.072)	(−1.747)	(−1.128)	(−0.934)
DItaly	26.833***	27.444***	−0.219***	−0.224***	−0.003	−0.534
	(12.432)	(12.219)	(−8.710)	(−8.756)	(−0.002)	(−0.249)
DUKingdom	10.188***	10.541***	−0.236***	−0.238***	3.292	2.854
	(7.228)	(7.325)	(−15.389)	(−15.378)	(1.520)	(1.300)
Adj. R^2	0.396	0.358	0.386	0.368	0.061	0.038
	F(6,430)	F(6,430)	F(6,430)	F(6,430)	F(6,430)	F(6,430)
	48.65***	41.65***	46.61***	43.37***	5.75***	3.84***
n	437	437	437	437	437	437

Notes: Heteroskedasticity-robust t values in parentheses.
* Significant at 0.10 level.
** Significant at 0.05 level.
*** Significant at 0.01 level.

the individual dimensions of Schumpeterian patterns of innovation seem to provide further support to this interpretation. In particular, looking at OLS estimates for *ENTRY* (see Table 4 columns 1 and 2), the coefficient of *OPPORTUNITY* is statistically significant in both specifications adopted here. Its positive sign indicates that a larger availability of external sources of knowledge raises the incentives for potential innovators to engage in innovative search, thus increasing the likelihood of innovative entry. Similarly, the coefficient of *OPPORTUNITY* in OLS estimates for *STABILITY* is statistically significant in both specifications adopted here. Moreover, its negative sign indicates that higher levels of technological opportunities, by encouraging the entry of new innovators, are also associated to less stable hierarchies of innovators. In OLS estimates for *C4*, however, the coefficient of *OPPORTUNITY* is never statistically significant. As we argued above, the impact of technological opportunity on the concentration ratio of innovative activities is likely to depend on the degree of appropriability of new knowledge. In order to test this hypothesis, we have considered the interaction between *OPPORTUNITY* and *APPROPRIABILITY* variables. Results from regression analysis (not reported here) confirm that higher technological opportunities have a negative and statistically significant impact on the concentration of innovative activities, but that such impact is less strong the more effective the appropriability conditions. Our interpretation of this result is that where technological opportunities are higher it is easier for new firms to try something that the leaders have not tried yet. This will reduce the rate of concentration of innovative activities as long as those firms coming up with innovations cannot exploit the current advantage for the next innovative round.[25]

5.1.2. *Appropriability and cumulativeness*

Turning to the role of appropriability and cumulativeness conditions, the coefficients of *APPROPRIABILITY* and *CUMULAT* are both significant at con-

[25] In order to test the effects of each individual source of technological opportunities, we reestimated our benchmark specification using the scores received by the five external sources of knowledge as independent variables. The results can be summarised as follows. The role of equipment suppliers and that of joint-ventures and alliances significantly affect the rate of innovative entry in a positive way and the stability in the ranking of innovative firms in a negative way. The former result is consistent with the finding that, where technical advances take place upstream in the vertical chain of production, downstream sectors are characterised by a fragmented industrial structure and therefore by lower degrees of stability in the ranking of innovative firms (Pavitt, 1984). The latter result indicates that small new entrants more often need to resort to a strategy of alliances and co-operation in order to acquire the requisite knowledge and the complementary assets relevant to their innovative activities (Teece, 1986). Regarding the role of users, the results indicate that the importance of new innovative firms tend to decline in sectors where users are important sources of new technical ideas and solutions. Although we had no prior expectations about the sign of this coefficient, this result may be interpreted as a demonstration of the fact that in sectors where user-producer interaction is important in devising new solutions, it may take time to develop the necessary trust and communication codes (Lundvall, 1993). In such a context, new entrants may therefore encounter problems in establishing long-run relationships with established users. Finally, no clear indication emerges with respect to the role of universities and public research laboratories.

ventional levels in nearly all specifications reported here.[26] In particular, the positive sign of both coefficients in the OLS and logit estimates for *SCHUMP* (see Table 3) supports the hypothesis according to which the ability to protect innovations from imitation and the extent to which present innovative efforts build upon past innovative activities are factors which increase the probability of observing a 'deepening' pattern of innovative activities (Schumpeter Mark II). These results are largely confirmed by regressions related to the individual dimensions of the Schumpeterian patterns of innovation. With respect to *ENTRY* (see Table 4), both coefficients are significantly different from zero and negatively associated with the share of innovations held by new firms, thus supporting the argument according to which in technological regimes where technical advances take place in a cumulative way small innovative entrants find themselves at a major disadvantage with respect to incumbents (Winter, 1984; Acs and Audretsch, 1988). Moreover, this result also suggests that a wider diffusion of technical knowledge (spillovers) has a positive effect on the probability of innovating for outside firms. With regard to *STABILITY* and *C4* (Table 4), the results are also consistent with the hypothesis of a positive impact of appropriability and cumulativeness conditions on the probability of observing a 'deepening' pattern of innovative activities. The coefficient of *APPROPRIABILITY* is always significantly different from zero across all specifications and it has the expected positive sign. This indicates that increasing degrees of appropriability bring about higher levels of concentration as well as higher degrees of stability in the ranking of innovative firms by limiting the extent of knowledge spillovers and by allowing successful innovators to maintain their competitive advantage over laggards.[27] Similarly, the extent to which technical advances in an industry are cumulative (*CUMULAT*) positively affects the rate of concentration of innovations, enhancing the importance of previously accumulated technological capabilities.

5.1.3. *Knowledge base*

Looking at Table 3, the coefficients of the variables representing the nature of the knowledge base are individually significant at conventional levels across all

[26] The most relevant exception is represented by *CUMULAT* whose coefficient, even though it shows the expected sign, is insignificant in OLS estimates for *STABILITY* (see Table 4).

[27] It should be pointed out that measuring appropriability as the *sum* of responses to questions on patents and secrecy could hide two separate effects. On the one hand, one could expect a deepening pattern even with weak patent protection as long as firms can protect their knowledge through secrecy. On the other hand, one could expect a widening pattern only when weak patent protection is combined with low effectiveness of secrecy in the protection of knowledge. In order to provide a first assessment of such effects, we tried to estimate regressions (not reported here) for *SCHUMP*, *ENTRY*, *STABILITY* and *C4*, using the scores on patents and secrecy as separate regressors. The coefficients of both explanatory variables are statistically significant at the conventional levels in all estimates (with the sole exception of secrecy in the OLS estimate for *STABILITY*) and they have the same sign. In particular, higher effectiveness in the protection of rents (i.e. patents) and of knowledge (i.e. secrecy) has a positive effect on the probability of observing a 'deepening' pattern of innovative activities (Schumpeter Mark II). The results remain unchanged even if we redefine *APPROPRIABILITY* as the maximum score received by any one of the two mechanisms for protecting innovation.

specifications and they have the expected sign. In particular, the positive coefficient of *BASSCIENCE* suggests that an increase in the importance of more generic and less targeted knowledge increases the probability of observing a 'deepening' pattern of innovative activities (Schumpeter Mark II). On the other hand, the negative coefficient of *APPSCIENCE* suggests that 'widening' patterns of innovation (Schumpeter Mark I) are most likely associated with an increasing importance of specific and more targeted forms of knowledge. These results are confirmed also by regression equations for the individual dimensions of Schumpeterian patterns of innovation (see Table 4). Broadly speaking, an increasing importance of product and process specific and targeted knowledge (APPSCIENCE) tends to bring about higher levels of innovative entry, lower degrees of stability and lower rates of concentration of innovations. Conversely, the sign of the coefficient of *BASSCIENCE* in the different regressions suggests that new innovative firms suffer a disadvantage with respect to incumbent firms in the assimilation and exploitation of publicly available generic and less targeted knowledge thus promoting a higher stability in the ranking of innovative firms and a higher rate of concentration of innovations.[28]

5.1.4. *Country effects and market structure*

Country fixed effects are statistically significant at the usual levels in regression equations for *ENTRY* and *STABILITY*. These results thus provide support to the hypothesis that the peculiar features of national systems of innovation crucially affect the overall importance of new entrants and the degree of creative accumulation across technological classes and, more generally, the Schumpeterian patterns of innovative activities. In particular, our results show that Italy and, to a less extent, United Kingdom have a more turbulent and less stable population of innovative firms compared to Germany.[29]

[28] These results are broadly in accordance with those found by Cohen and Levinthal (1989). Using Yale survey data, they found that increasing importance of less targeted basic sciences elicits more R&D spending than does increasing importance of applied sciences. They also suggest that the reason for this result is that, because basic science is less targeted to the needs and concerns of the firm, a firm must invest more to assimilate and exploit it. In our context, we can provide a similar interpretation by saying that in such circumstances (i.e. when generic knowledge is relevant), the probability of innovating is higher for firms which already innovated and possess the requisite absorptive capabilities (cumulatively built up over time), therefore discouraging the entry of new innovative firms and contributing to maintain a stable hierarchy of innovative firms. This eventually increases concentration through the selection of less successful firms.

[29] In order to test the robustness of our results, we estimated our benchmark specification including also market structure variables, such as the average value added and the ratio between the number of patenting firms and the total number of active firms. The results (not reported here) show that, as expected, average value added has a positive and statistically significant coefficient in regressions for *SCHUMP* (suggesting that high barriers to entry in product markets positively affect the probability of observing a deepening pattern of innovation). The ratio between the number of patenting firms and the total number of active firms has a negative and significant coefficient in regressions for *SCHUMP* (indicating that a wider base of innovative firms relative to the number of firms active in an industry is negatively associated to a deepening pattern of innovation). However adding such variables has only a marginal impact on the estimated coefficients of technological regime variables.

6. Conclusions

This paper proposed that the specific pattern of innovative activity in an industry can be explained as the outcome of different *technological* (learning) *regimes* that are implied by the nature of technology. Building on the distinction between Schumpeter Mark I and Schumpeter Mark II technologies and on previous empirical results showing that patterns of innovative activities are remarkably similar across countries in the same technological class, we proposed estimates of the relationships between indicators of Schumpeterian patterns of innovation (concentration of innovative activities, stability in the hierarchy of innovators, relevance of new innovators, and a summary variable obtained through principal components analysis that defines whether a technological class is more similar to a Schumpeter Mark I or to a Schumpeter Mark II pattern) and indicators of the variables defining technological regimes. The former indicators are based on European patent data for three countries (United Kingdom, Germany and France). A technological regime is defined as a particular combination of opportunity, appropriability, cumulativeness conditions and properties of the knowledge base (specific vs. generic nature of the relevant knowledge base). Measures of these variables were obtained by the PACE questionnaire survey.

Results of the analysis provide considerable support to the hypothesis that the sectoral patterns of technical change are related to the nature of the underlying technological regime. In particular, Schumpeter Mark II patterns (characterised by high degrees of concentration of innovative activities, high stability in the ranking of innovators and low relevance of new innovators) are related to high degrees of cumulativeness and appropriability, high importance of basic sciences and relatively low importance of applied sciences as sources of innovation. Schumpeter Mark I patterns (characterised by low concentration of innovative activities, low stability in the ranking of innovators and high relevance of new innovators) are related to low degrees of cumulativeness and appropriability, and high importance of applied sciences and an increasing role of external sources of knowledge.

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References

Acs, Z. J. and Audretsch, D. B. (1988). 'Innovation in large and small firms: an empirical analysis.' *American Economic Review*, vol. 78, no. 4, pp. 678–690.

Arundel, A., van de Paal, G. and Soete, L. (1995). 'Innovation strategies of Europe's largest industrial firms: results of the PACE survey for information sources, public research, protection of innovations and government programmes.' Report for the SPRINT Programme, DG XIII EC, MERIT Institute, University of Limburg.

Audretsch, D. B. (1995). *Innovation and Industry Evolution.* Cambridge MA: MIT Press.

Breschi, S. and Malerba, F. (1997). 'Sectoral innovation systems: technological regimes, Schumpeterian dynamics and spatial boundaries'. In (C. Edquist, ed.) *Systems of Innovation. Technologies, Institutions and Organisation*, pp. 130–56. London: Cassell.

Christensen, C. M. and Rosenbloom, R. (1995). 'Explaining the attacker's advantage: technological paradigms, organisational dynamism and the value network.' *Research Policy*, vol. 24, no. 2, pp. 233–57.

Cohen, W. M. (1995). 'Empirical studies of innovative activities.' In (P. Stoneman, ed.) *Handbook of the Economics of Innovation and Technological Change,* pp. 182–264, Oxford: Blackwell.

Cohen, W. M. and Levin, R. C. (1989). 'Empirical studies of innovation and market structure.' In (R. Schmalensee and R. Willig, eds.) *Handbook of Industrial Organisation,* pp. 1059–107, Amsterdam: North Holland.

Cohen, W. M., Levin, R. C. and Mowery, D. C. (1987). 'Firm size and R&D intensity: a re-examination.' *Journal of Industrial Economics*, vol. 35, no. 4, pp. 543–65.

Cohen, W.M. and Levinthal, D.A. (1989). 'Innovation and learning: the two faces of R&D.' ECOMOMIC JOURNAL, vol. 99 (September), pp. 569–96.

Dasgupta, P. and Stiglitz, J. (1980). 'Industrial structure and the nature of innovative activity.' ECONOMIC JOURNAL, vol. 90, (June), pp. 266–93.

Dosi, G. (1982). 'Technological paradigms and technological trajectories. a suggested interpretation of the determinants and directions of technical change.' *Research Policy*, vol. 11, no. 3, pp. 147–62.

Dosi, G. (1988). 'The microeconomic sources and effects of innovation.' *Journal of Economic Literature,* vol. 26, no. 3, pp. 1120–71.

Dosi, G., Marsili, O., Orsenigo, L. and Salvatore, R. (1995). 'Technological regime, selection and market structure.' *Small Business Economics*, vol. 7, no. 4, pp. 411–36.

Gilbert, R. and Newbery, D. (1982). 'Preemptive patenting and the persistence of monopoly.' *American Economic Review*, vol. 72, no. 3, pp. 514–26.

Gort, M. and Klepper, S. (1982). 'Time paths in the diffusion of product innovations.' ECONOMIC JOURNAL, vol. 92, (September), pp. 630–53.

Griliches, Z. (1990). 'Patent statistics as economic indicators: a survey.' *Journal of Economic Literature* vol. 28, no. 4, pp. 1661–707.

Henderson, R. and Clark, K. (1990). 'Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms.' *Administrative Science Quarterly,* vol. 35, (March), pp. 9–30

Iwai, K. (1984*a*). 'Schumpeterian dynamics part I: an evolutionary model of selection and imitation.' *Journal of Economic Behaviour and Organisation*, vol. 5, no. 2, pp. 159–90.

Iwai, K. (1984*b*). 'Schumpeterian dynamics part II: technological progress, firm growth and economic selection.' *Journal of Economic Behaviour and Organisation*, vol. 5, no. 3–4, pp. 321–51.

Jovanovic, B. (1982). 'Selection and evolution of industry.' *Econometrica*, vol. 50, no. 3, pp. 649–70.

Jovanovic, B. and Lach, S. (1988). 'Entry, exit and diffusion with learning-by-doing.' *American Economic Review*, vol. 79, no. 4, pp. 690–9.

Kamien, M. I. and Schwartz, N. L. (1982). *Market Structure and Innovation.* Cambridge: Cambridge University Press.

Klepper, S. (1996). 'Entry, exit, growth and innovation over the product life cycle.' *American Economic Review*, vol. 86, no. 3, pp. 562–83.

Klevorick, A. K., Levin, R. C., Nelson, R. R. and Winter, S. G. (1995). 'On the sources and significance of interindustry differences in technological opportunities.' *Research Policy*, vol. 24, no. 2, pp. 185–205.

Levin, R. C. (1988). 'Appropriability, R&D spending and technological performance.' *American Economic Review, Papers and Proceedings*, vol. 78, no. 2, pp. 424–8.

Levin, R. C., Cohen, W. M. and Mowery, D. C. (1985). 'R&D, appropriability, opportunity, and market structure: New evidence on some schumpeterian hypotheses.' *American Economic Review, Papers and Proceedings,* vol. 75, no. 2, pp. 20–4.

Levin, R. C., Klevorick, A. K., Nelson, R. R. and Winter, S. G. (1987). 'Appropriating the returns from industrial research and development.' *Brookings Papers on Economic Activity*, 3, pp. 783–820.

Levin, R. C. and Reiss, P. C. (1988). 'Cost-reducing and demand creating R&D with spillovers.' *Rand Journal of Economics*, vol. 19, no. 4, pp. 538–56.

Malerba, F. and Orsenigo, L. (1990). 'Technological regimes and patterns of innovation: a theoretical and empirical investigation of the Italian case'. In (A. Heertje and M. Perlman, eds.) *Evolving Technologies and Market Structure*, pp. 283–306, Ann Arbor: Michigan University Press.

Lundvall, B. A. (1993). *National Systems of Innovation.* London: Pinter.

Malerba, F. and Orsenigo, L. (1993). 'Technological regimes and firm behaviour.' *Industrial and*

Corporate Change, vol. 2, no. 1, pp. 45–71.
Malerba, F. and Orsenigo, L. (1994). 'Schumpeterian patterns of innovation.' *Cambridge Journal of Economics*, vol. 19, no. 1, pp. 47–66.
Malerba, F. and Orsenigo, L. (1996). 'Schumpeterian patterns of innovation are technology specific.' *Research Policy*, vol. 25, no. 3, pp. 451–78.
Malerba, F. and Orsenigo, L. (1999). 'Technological entry, exit and survival.' *Research Policy*, vol. 28, no. 6, pp. 643–60.
Nelson, R. R. (1993). *National Innovation Systems.* Oxford: Oxford University Press.
Nelson, R. R. (1995). 'Recent evolutionary thinking about economic change.' *Journal of Economic Literature*, vol. 33, (March), pp. 48–90.
Nelson, R. R. and Winter, S. (1982). *An Evolutionary Theory of Economic Change.* Cambridge (Mass.): The Belknap Press of Harvard University Press.
Pavitt, K. (1984). 'Sectoral patterns of innovation: towards a taxonomy and a theory.' *Research Policy* vol. 13, no. 6, pp. 343–73.
Pavitt, K., Robson, M. and Townsend, J. (1987). 'The size distribution of innovating firms in the UK: 1945-83.' *Journal of Industrial Economics*, vol. 35, no. 3, pp. 297–316.
Rosenberg, N. (1982). *Inside the Black Box.* Cambridge: Cambridge University Press.
Rosenberg, N. (1990). 'Why do firms do basic research (with their own money)?.' *Research Policy*, vol. 19, no. 2, pp. 165–74.
Schumpeter, J. A. (1934). *The Theory of Economic Development.* Cambridge Mass.: Harvard Economic Studies.
Schumpeter, J. A. (1942). *Capitalism, Socialism and Democracy.* New York: Harper and Brothers.
Teece, D. J. (1986). 'Profiting from technological innovation: implications for integration, collaboration, licensing and public policy.' *Research Policy*, vol. 15, no. 6, pp. 286–305.
Utterback, J. M. and Abernathy, W. J. (1975). 'A dynamic model of product and process innovation.' *Omega*, vol. 3, no. 6, pp. 639–56.
Winter, S. G. (1984). 'Schumpeterian competition in alternative technological regimes.' *Journal of Economic Behavior and Organization*, vol. 5, (September–December), pp. 287–320.
Winter, S. G. (1987). 'Knowledge and competence as strategic assets'. In (D. J. Teece, ed.) *The Competitive Challenge: Strategies for Industrial Innovation and Renewal*, pp. 159–84, Cambridge Mass.: Ballinger.
World Intellectual Property Organization (1994). *International Patent Classification (6th Edition)*, Geneve.