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Schumpeterian patterns of innovation

Franco Malerba* and Luigi Orsenigo*

Using patent data for four countries (Germany, France, United Kingdom and Italy) for the period 1968–1986, the authors find that the patterns of innovative activities differ systematically across technological classes, while remarkable similarities emerge across countries in the patterns of innovative activities for each technological class. This result strongly suggests that 'technological imperatives' and technology-specific factors (closely linked to technological regimes) play a major role in determining the patterns of innovative activities across countries.

1. Schumpeter Mark I or Schumpeter Mark II?

In *The Theory of Economic Development* and in *Capitalism, Socialism and Democracy*, Schumpeter proposed two major patterns of innovative activities. The first one, labelled by Nelson and Winter (1982) and Kamien and Schwartz (1982) as Schumpeter Mark I, is proposed in *The Theory of Economic Development* (1934). In this work, Schumpeter examined the typical European industrial structure of the late nineteenth century characterised by many small firms. According to this view, the pattern of innovative activity is characterised by technological ease of entry in an industry and by a major role played by new firms in innovative activities. New entrepreneurs come in an industry with new ideas, new products or new processes, launch new enterprises which challenge established firms and thus continuously disrupt the current ways of production, organisation and distribution and wipe out the quasi rents associated with previous innovations.

The second one, labelled Schumpeter Mark II, is proposed in *Capitalism, Socialism and Democracy* (1942). In this work, inspired by the features of the American industry of the first half of the twentieth century, Schumpeter discussed the relevance of the industrial R&D laboratory for technological innovation and the key role of large firms. According to this view, the pattern of innovative activities is characterised by the prevalence of large established firms and by relevant barriers to entry for new innovators. Large firms have institutionalised the innovation process with the creation of R&D laboratories filled with researchers, technicians and engineers. With their accumulated stock of knowledge in specific technological areas, their advanced competence in large scale R&D projects, production and distribution and their relevant financial resources, they create barriers to entry to new entrepreneurs and small firms.

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The Schumpeterian Mark I and Mark II patterns of innovation could also be labelled as '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 the erosion of the competitive and technological advantages of the established firms in the industry. A deepening pattern of innovation, however, is related to the dominance of a few firms which are continuously innovative through the accumulation over time of technological and innovative capabilities. During the last forty years this characterisation 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). Extensive empirical analyses have been done in order to verify the innovativeness of small firms vs. large firms and of concentrated industries vs. atomistic industries. The inconclusive results obtained in these empirical analyses are due to the neglected role of opportunity and appropriability conditions in the various industries (Levin, Cohen and Mowery, 1985) and of the endogenous relationship between firm size, concentration and technological change (Nelson and Winter, 1982).

A second, and more recent, tradition has inserted Schumpeter Mark I and II models according to the specific stage of an industry life cycle. 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 are the key element in industrial dynamics. However, when 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 and large firms with monopolistic power come to the forefront of the innovation process (Utterback and Abernathy, 1975; Gort and Klepper 1982; Klepper, 1992).

Differently from the traditions centred on the firm and on industry life cycles, the present paper aims to discuss the widening and deepening Schumpeterian patterns of innovation across industries by focussing on the way innovative activities are organised and take place within an industry. The starting point of this paper is that the Schumpeterian widening and the Schumpeterian deepening patterns of innovative activities are related to the key features of the technological régime which characterise an industry.

Inspired by Nelson and Winter (1982), Dosi (1988) and Cohen and Levin (1989), who have pointed out that the conditions of opportunity and appropriability may greatly affect the way innovative activities are carried out in an industry in terms of firm size and industrial concentration, we (Malerba and Orsenigo, 1990, 1993) have defined technological régimes in terms of opportunity, appropriability, cumulativeness and properties of the knowledge base. We have examined the link between technological régimes and patterns of innovative activities both at the conceptual and the empirical levels. Opportunity conditions refer to the ease of innovation by would-be innovators, and are related to the potential for innovation of each technology. Appropriability conditions refer to the ability of innovators to protect their innovations from imitation, and therefore to reap results and profits from their innovations. Cumulativeness conditions refer to the fact that existing innovators may continue to be so also in the future with respect to non-innovators. Finally, knowledge base conditions refer to the number and type of basic and applied sciences necessary to innovative activities, and to the tacit or codified, simple or complex, specialised or pervasive, dimensions of knowledge underpinning innovation in an industry.

According to the above-mentioned analysis based on technological régimes, the widening and deepening Schumpeterian patterns of innovation may be seen as the results of well-defined régime conditions. Widening patterns are determined by high opportunity and low appropriability conditions, which favour the continuous entry of new innovators in the industry, and by low cumulativeness conditions, which do not allow the persistence of monopolistic advantages in the industry innovators. Deepening patterns are determined by high opportunity, appropriability and cumulativeness conditions, which allow innovators to accumulate technological knowledge and capabilities continuously and to build up innovative advantages over non-innovators and potential entrants (Malerba and Orsenigo, 1993).[1]

Of course, widening and deepening Schumpeterian patterns of innovative activities are two extreme cases that delineate a large number of intermediate cases. These intermediate cases have been discussed at length in Malerba and Orsenigo (1990). Moreover, as previously mentioned, during their life cycles industries may change patterns of innovative activity, passing from a Schumpeter Mark I to a Schumpeter Mark II type of model.

It must be noted that the claim that technological régimes affect the type of Schumpeterian patterns of innovative activities implies that these patterns of innovations ought to be relatively invariant across countries. This is so because the appropriability and cumulativeness conditions, the two dimensions of technological régimes that affect the widening and deepening patterns of innovation, are fairly similar across advanced industrialised countries (see Malerba and Orsenigo, 1990 and Heimler, Malerba and Peretto, 1993, for an analysis of the Italian and American cases). Opportunity conditions among advanced countries are less similar, because these conditions are 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 type-level of firms' innovative efforts (Nelson, 1993).

This paper represents the first empirical analysis of the widening and deepening Schumpeterian patterns of innovation carried out at the firm level for 33 technological classes and for four countries: Germany (Federal Republic), France, the United Kingdom and Italy. Section 2 discusses the data used for the analysis. Section 3 examines the single indicators used to identify the two Schumpeterian patterns of innovation. Section 4 then analyses the two Schumpeterian patterns while Section 5 discusses the relationships between the patterns of innovation and technological performance.

2. The data

Patent data have been used to investigate the two Schumpeterian patterns of innovation. Criticisms of the use of patent data are well known. Not all innovations are patented by firms. Patents cannot be distinguished in terms of relevance unless specific analyses on patent renewals or patents citations are done. Finally, different technologies are differently patentable and different types of firms may have different propensities to patent. However, patents represent an homogeneous measure of technological novelty across countries and are available for long time series. They also provide very detailed

[1] Malerba and Orsenigo (1993) provide a full discussion of these relationships and some examples taken from specific industries.

data at the firm and the technological class levels. As a consequence, they are an invaluable and unique source of data on innovative activity. As Griliches (1990) has pointed out, 'patents statistics remain a unique resource for the analysis of the process of technical change. Nothing else even comes close in the quality of available data, accessibility, and the potential industrial, organisational and technological detail'.

This paper has used the OTAF-SPRU data base which concerns patents granted in the United States to firms and institutions from all over the world.[1] The OTAF-SPRU data base has been elaborated at the firm level for four European countries: Germany (Federal Republic), France, the United Kingdom and Italy. These countries represent a fairly heterogeneous data set, with some countries at the technological frontier and others lagging behind. Extreme cases have not been taken into consideration: neither the United States, which may over-represent small firms and a higher propensity to patent of firms at the local United States Patent Office, nor Japan, which, given its high growth rate of patents during the period, may given distorted indications of the average pattern of innovative activities during a long period of time.

The analysis has been carried out for the period 1969–1986. Given this long period of time, it is possible that a technological class may have moved over the period from a Schumpeter Mark I group to a Schumpeter Mark II group. Thirty-three technological classes are considered in the analysis (see the Appendix) including Class 33 'Other' (ammunitions, road structure, plant and animal husbandry, and others). Economic data on firms patenting in the United States concerns size in term of employees in 1984. Therefore, a bias may be present in the analysis in favour of firms active during the 1980s. Firms which are part of business groups have been treated in the present analysis as individual companies. It must be noted that we carried out an analysis[2] which considered industrial groups rather than individual firms: this confirmed the main results of this paper.

3. Indicators of Schumpeterian patterns of innovative activities

Using patent data, the present analysis has constructed a group of indicators of the Schumpeterian patterns of innovative activities. These indicators, examined individually in this section, will be used jointly in Section 4 to identify those technological classes which belong either to a Schumpeterian widening pattern or to a Schumpeterian deepening pattern of innovative activity.

The indicators of pattern of innovative activities used in the present analysis can be grouped in four types. For each of the 33 technological classes, this paper has built indicators of:

A. Concentration of innovative activities (concentration ratio of the top 4 innovators) and asymmetries among innovators (Herfindahl index);

B. Size of the innovating firms;

C. Change over time in the hierarchy of firms which innovate continuously;

D. Relevance of new innovators as compared to established ones.

In addition, two further indicators, one of structure and the other of performance, have been used:

E. Composition of innovative activities within each of the four countries;

F. World technological performance of the four countries in a given technological class.

[1] We wish to thank Keith Pavitt and Pari Patel of SPRU who allowed us to use this data base.

[2] Details may be obtained from the authors

While indicators such as concentration (A) and firm size (B) have been generally used in traditional discussions of the Schumpeterian hypotheses, in this paper two additional indicators, the change in the hierarchy of innovators (C) and the relevance of new innovators (D), are proposed. The two new indicators (E) and (F) aim to shed light on the degree of 'stability' or 'dynamism' in the organisation of innovative activity at the industry level, in terms of degree of change in the hierarchy of the main innovators and relevance of firms that introduce innovations for the first time. These indicators are able to capture the degree of 'creative destruction' or the degree of 'creative accumulation' associated with innovative activities.

In the following pages the meaning, construction and results of the various indicators of patterns of innovative activities are discussed briefly.

3.1. Concentration and asymmetries (C4 and HERFINDAHL)

A first indicator of patterns of innovative activities is the degree of concentration of innovations among leading innovators. In this paper, the share of patents held by the four major innovators within each technological class is used (C4). In addition to the concentration ratio C4, a second indicator has been used to identify the degree of asymmetries among all the innovators (large and small) in a technological class: the Herfindahl index (HERFINDAHL).

C4 has a high value on average in the four countries. It is consistently high in the chemical group and consistently low in the mechanical group. There is more variability in the electronic-electrical group, especially because the United Kingdom shows a much lower concentration ratio than the other three countries (see Table 1). This result indicates that oligopolistic structures dominate innovative activities in most technological classes.

HERFINDAHL, on the contrary, has low values on average. It is consistently high (therefore indicating the presence of asymmetries) in the electronics group and in the chemical group; it is consistently low (therefore indicating similarities across firms) in the mechanical group and instrumentation; it has medium values or variability in the values across countries in autos and drugs (see Table 1).

In addition, the Pearson correlation coefficient (not reported here) show a striking similarity in the level of C4 and HERFINDAHL for each technological class across countries and the Spearman rank correlation coefficient (also not reported here) highlights a similar hierarchy of technological classes in the four countries.

3.2. Size of the innovating firms (SIZE)

A second group of indicators, still in the Schumpeterian tradition, refers to the size of innovative firms. In this paper, patenting firms with more than 500 employees have been considered for each technological class for Germany, France, the United Kingdom and Italy. As expected, among the four countries Italy has on average the lower share of patents held by large firms and Germany the largest, with France in the middle (see Table 2). Among technological classes, the mechanical and machinery groups and textiles show the greatest relevance of small firms in innovative activities.

Analysis of country-differences based on Pearson and Spearman correlation coefficients (not reported here) show again a striking similarity in the importance of large innovative firms in the 33 technological classes and a very similar ranking of technological classes across countries.

Table 1. *Concentration ratio (C4) and Herfindahl Index by technological classes and country*

	C4						HERFINDAHL					
Code	Italy	FRG	France	UK	AVG[a]	STD[b]	Italy	FRG	France	UK	AVG[a]	STD[b]
1	72·3	45·9	52·3	36·8	51·8	13·0	0·18	0·06	0·09	0·06	0·10	0·05
2	48·9	71·3	48·3	47·6	54·0	10·0	0·09	0·18	0·07	0·13	0·12	0·04
3	90·0	87·1	70·6	75·9	80·9	7·9	0·40	0·25	0·16	0·21	0·26	0·09
4	34·1	36·2	26·3	28·7	31·3	4·0	0·04	0·04	0·03	0·04	0·04	0·01
5	74·4	46·0	76·5	73·0	67·5	12·5	0·25	0·08	0·38	0·20	0·23	0·11
6	47·4	77·7	78·3	69·0	68·1	12·5	0·08	0·19	0·34	0·22	0·21	0·09
7	38·4	59·6	43·9	44·3	46·5	7·9	0·06	0·14	0·07	0·07	0·09	0·03
8	48·2	36·0	54·6	50·5	47·3	6·9	0·08	0·05	0·16	0·09	0·09	0·04
9	24·0	29·5	23·7	33·1	27·6	3·9	0·03	0·03	0·02	0·04	0·03	0·01
10	53·6	47·9	37·2	42·0	45·2	6·1	0·13	0·14	0·05	0·07	0·09	0·04
11	27·9	22·4	19·9	18·4	22·2	3·6	0·03	0·02	0·02	0·01	0·02	0·01
12	24·4	14·8	17·8	16·6	18·4	3·6	0·02	0·01	0·01	0·01	0·02	0·00
13	25·2	24·6	29·8	29·6	27·3	2·4	0·04	0·03	0·03	0·03	0·03	0·00
14	30·3	43·5	28·9	22·6	31·4	7·6	0·03	0·07	0·03	0·02	0·04	0·02
15	18·1	10·5	14·8	16·0	14·8	2·8	0·01	0·01	0·01	0·01	0·01	0·00
16	23·0	18·7	21·8	12·9	19·1	3·9	0·02	0·01	0·02	0·01	0·02	0·01
17	27·9	17·3	17·6	17·5	20·1	4·5	0·03	0·01	0·02	0·01	0·02	0·01
18	85·0	81·3	93·2	86·8	86·6	4·3	0·34	0·20	0·47	0·40	0·35	0·10
19	49·1	42·5	45·2	68·2	51·3	10·1	0·09	0·06	0·10	0·20	0·11	0·05
20	49·0	70·4	44·1	41·8	51·3	11·3	0·09	0·23	0·07	0·08	0·12	0·06
21	22·7	32·6	24·4	16·7	24·1	5·7	0·03	0·05	0·03	0·01	0·03	0·01
22	83·3	73·9	50·7	60·6	67·1	12·5	0·22	0·24	0·09	0·10	0·16	0·07
23	54·0	55·6	48·5	32·4	47·6	9·2	0·10	0·14	0·08	0·05	0·09	0·03
24	65·0	66·5	52·1	32·4	54·0	13·7	0·15	0·31	0·10	0·04	0·15	0·10
25	69·2	90·3	76·3	45·9	70·4	16·1	0·19	0·61	0·22	0·09	0·28	0·20
26	29·5	57·2	39·4	28·2	38·6	11·6	0·04	0·22	0·07	0·03	0·09	0·08
27	80·6	58·1	55·1	26·7	55·1	19·1	0·36	0·17	0·11	0·03	0·17	0·12
28	43·8	65·2	56·6	27·3	48·2	14·3	0·07	0·13	0·16	0·04	0·10	0·05
29	81·1	80·5	48·4	47·9	64·5	16·3	0·22	0·36	0·09	0·07	0·19	0·12
30	28·7	34·9	33·2	13·5	27·6	8·4	0·03	0·06	0·04	0·01	0·03	0·02
31	12·9	11·3	20·3	8·2	13·2	4·4	0·01	0·01	0·02	0·01	0·01	0·00
32	39·5	35·3	41·4	14·1	32·6	10·9	0·06	0·05	0·06	0·01	0·04	0·02
33	33·3	45·5	39·2	29·2	36·8	6·1	0·04	0·07	0·06	0·04	0·05	0·01

[a]Average. [b]Standard deviation.

3.3. Change in the hierarchy of innovators and entry in the core group of innovators (SPEA and NEWLEADERS)

A different set of indicators refers to the change or the constancy in the hierarchy of firms which innovate in both periods (1969–1977 and 1978–1986) and of the leading innovators. These indicators aim to shed light on the degree of stability of technological advantage of the leading innovators and consequently on the degree of dynamism of the population of innovators.

In this respect, two indicators have been used for each technological class. The first one is the Spearman rank correlation coefficient between the hierarchy of firms innovating in both periods (1969–1977 and 1978–1986) (SPEA). The second is the share of patents held by the firms entering for the first time the group of the ten major innovators in the period 1978–1986 with respect to the period 1969–1977 (NEWLEADERS).

Table 2. *Innovative activities of medium-sized and large firms[a] (SIZE) by technological class and country*

Code	Italy	FRG	France	UK	AVG	STD
1	76·79	80·05	90·11	74·92	80·47	5·86
2	72·48	93·60	87·14	83·36	84·15	7·67
3	96·67	96·10	78·43	95·97	91·79	7·72
4	52·63	81·39	77·38	74·01	71·35	11·12
5	78·21	82·70	87·24	84·04	83·05	3·25
6	55·26	91·58	85·94	90·21	80·75	14·86
7	59·89	91·38	68·08	86·98	76·58	13·02
8	43·22	81·23	80·96	77·85	70·81	15·99
9	41·67	81·28	78·04	67·61	67·15	15·56
10	55·95	79·45	67·15	75·12	69·42	8·94
11	33·50	77·37	79·90	62·03	63·20	18·46
12	47·65	66·64	63·14	56·45	58·47	7·24
13	54·49	81·66	73·31	76·82	71·57	10·30
14	55·45	77·39	76·31	67·11	69·06	8·81
15	41·15	67·16	62·64	52·64	55·90	10·01
16	44·31	65·13	76·48	51·83	59·44	12·35
17	49·25	63·29	65·65	59·61	59·45	6·27
18	35·00	79·82	94·20	99·26	77·07	25·31
19	59·65	93·67	80·78	89·90	81·00	13·19
20	74·75	96·49	78·21	83·17	83·15	8·26
21	45·45	80·65	63·90	56·28	61·57	12·82
22	66·67	96·18	75·36	71·76	77·49	11·22
23	61·90	48·37	75·26	53·09	59·66	10·23
24	84·74	89·07	81·79	64·62	80·06	9·28
25	49·23	94·18	85·53	78·31	76·81	16·89
26	58·48	86·79	81·51	69·55	74·08	10·96
27	90·54	88·10	83·33	75·53	84·37	5·73
28	73·44	88·33	87·08	57·87	76·68	12·33
29	15·57	92·76	64·21	87·71	65·06	30·54
30	57·47	80·57	76·26	66·30	70·15	8·96
31	25·63	60·78	70·32	49·63	51·59	16·68
32	10·48	69·72	62·50	40·84	45·89	23·04
33	22·55	74·34	66·79	55·14	54·71	19·79

[a]Share of total patents held by firms with more than 500 employees.

As Table 3 shows, there are differences among countries in terms of degree of change in the hierarchy of innovators in each technological class (SPEA) and in the ranking of technology classes in terms of stability. France and the United Kingdom are very similar in the level and ranking of changes in the hierarchy within technological classes, while Germany and Italy are very different in level and ranking of technological classes.

In some technological classes, however, this indicator takes in all countries consistently high values (i.e. some classes of chemicals and electronics and road vehicles) or consistently low values (bleaching, dyeing and disinfecting, non-metallic minerals and other materials, some mechanical sectors, other transport, mining and well machinery, metal products and textiles).

On average the degree of stability over time in the hierarchy of innovators (SPEA) is high and similar for Germany, France and the United Kingdom (Italy has a lower value). The entry in the group of core innovators in each technological class (NEWLEADERS) shows that Germany has the lowest level of entry and Italy the highest (see Table 3).

Table 3. *Variability of the hierarchy: share of total patents of the 10 most innovative firms held by firms entering the top 10 group (NEWLEADERS) in the period 1978/1986 and Spearman Rank correlation coefficient of firms which innovate continuously (SPEA), by technological classes and country*

	NEWLEADERS						SPEA					
Code	Italy	FRG	France	UK	AVG	STD	Italy	FRG	France	UK	AVG	STD
1	33·3	12·0	36·8	16·9	24·7	10·5	0·69	0·35	0·50	0·68	0·56	0·14
2	2·2	2·0	16·1	3·4	5·9	5·9	0·47	0·61	0·57	0·51	0·54	0·06
3	16·7	6·0	63·6	5·9	23·0	23·8	0·00	0·64	1·00	0·88	0·63	0·39
4	5·3	3·8	0·0	7·2	4·1	2·7	0·57	0·54	0·56	0·69	0·59	0·06
5	65·2	13·0	14·2	24·7	29·3	21·3	0·00	0·49	0·71	0·67	0·46	0·28
6	62·5	12·0	7·3	18·9	25·2	21·9	− 1·00	0·64	0·23	0·41	0·07	0·63
7	18·8	3·0	7·1	13·2	10·5	6·0	0·36	0·66	0·51	0·83	0·59	0·17
8	63·2	7·1	7·1	9·8	21·8	23·9	0·44	0·70	0·57	0·47	0·55	0·10
9	59·5	9·5	14·2	0·0	20·8	22·9	0·03	0·58	0·33	0·25	0·30	0·19
10	87·0	20·7	35·1	8·9	37·9	29·8	1·00	0·47	0·65	0·79	0·73	0·19
11	36·6	0·0	0·0	20·8	14·3	15·4	0·39	0·53	0·48	0·65	0·51	0·10
12	16·3	0·0	23·9	0·0	10·1	10·4	0·48	0·50	0·53	0·48	0·50	0·02
13	44·2	0·0	21·1	11·4	19·2	16·3	0·52	0·51	0·69	0·48	0·55	0·08
14	18·5	0·0	14·7	4·5	9·4	7·5	0·61	0·60	0·50	0·47	0·54	0·06
15	16·0	23·6	0·0	15·6	13·8	8·6	0·52	0·54	0·47	0·34	0·47	0·08
16	28·9	0·0	16·7	28·0	18·4	11·7	0·37	0·49	0·65	0·61	0·53	0·11
17	44·8	10·1	8·2	14·0	19·3	14·9	0·47	0·57	0·20	0·42	0 42	0 14
18	100·0	6·1	10·7	14·0	32·7	39·0	0·00	0·45	0·50	1·00	0·49	0·35
19	54·5	0·0	4·5	13·3	18·1	21·6	− 0·18	0·72	0·67	0·79	0·50	0·40
20	43·8	0·0	11·2	20·5	18·9	16·1	0·66	0·77	0·74	0·39	0·64	0·15
21	58·3	5·7	37·3	37·3	34·7	18·8	0·41	0·64	0·41	0·25	0·43	0·14
22	100·0	21·6	10·2	61·7	48·4	35·4	0·00	0·52	0·48	0·80	0·45	0·29
23	47·4	9·9	41·1	12·7	27·8	16·7	0·90	0·29	0·74	0·42	0·59	0·24
24	24·8	3·0	5·0	6·3	9·8	8·8	0·47	0·53	0·77	0·67	0·61	0·12
25	29·0	6·4	3·8	15·2	13·6	9·9	0·00	0·84	0·56	0·53	0·48	0·30
26	29·3	3·9	5·0	4·6	10·7	10·8	0·32	0·42	0·63	0·58	0·49	0·13
27	6·2	5·6	0·0	10·4	5·6	3·7	0·86	0·56	0·79	0·63	0·71	0·12
28	66·7	1·4	5·7	16·0	22·5	26·1	− 0·50	0·81	0·69	0·27	0·32	0·51
29	11·5	1·5	51·1	6·8	17·7	19·6	0·97	0·67	0·36	0·03	0·51	0·35
30	33·3	0·0	0·0	6·3	9·9	13·8	0·71	0·63	0·67	0·49	0·63	0·08
31	31·5	0·0	0·0	21·4	13·2	13·7	0·69	0·38	0·60	0·40	0·52	0·13
32	86·3	17·9	70·8	79·2	63·5	26·9	0·98	0·38	0·58	0·41	0·59	0·24
33	38·9	10·0	11·4	30·6	22·7	12·4	0·62	0·72	0·53	0·25	0·53	0·17

However, there is a similarity in the ranking of technological classes in terms of share of patents held by the new innovators in the top ten leading innovators for Germany, Italy and the United Kingdom, but not for France, as indicated by analysis based on the Pearson and Spearman correlation coefficients (not reported here).

3.4. New innovators (NATALITY)

One last set of measures concerns the relevance of new innovators in each technological class. The indicator used is the share of patents granted to firms that patent for the first time in the period 1978–86 with respect to the period 1969–1977 (NATALITY). It must be noted that this index measures innovative birth and not entrepreneurial birth: a new innovator may in fact have been around in the industry for quite a long time already. This measure may provide distorted information for those technological classes in which very few patents are present (such as agricultural chemicals, nuclear reactors and systems,

Table 4. *Index of new innovators* by technological classes and country*

Code	Italy	FRG	France	UK	AVG	STD
1	0·39	0·24	0·44	0·31	0·34	0·08
2	0·25	0·05	0·26	0·17	0·18	0·09
3	0·17	0·08	0·64	0·12	0·25	0·22
4	0·46	0·16	0·29	0·32	0·31	0·11
5	0·69	0·30	0·17	0·34	0·37	0·19
6	0·65	0·18	0·12	0·34	0·32	0·20
7	0·38	0·09	0·20	0·19	0·21	0·11
8	0·74	0·36	0·34	0·42	0·47	0·16
9	0·77	0·32	0·48	0·42	0·50	0·17
10	0·89	0·36	0·54	0·32	0·53	0·23
11	0·65	0·31	0·37	0·49	0·45	0·13
12	0·59	0·26	0·48	0·45	0·44	0·12
13	0·60	0·21	0·31	0·36	0·37	0·15
14	0·55	0·17	0·29	0·35	0·34	0·14
15	0·55	0·32	0·41	0·47	0·44	0·08
16	0·62	0·26	0·49	0·55	0·48	0·14
17	0·71	0·33	0·43	0·52	0·50	0·14
18	1·00	0·10	0·11	0·14	0·34	0·38
19	0·57	0·15	0·22	0·26	0·30	0·16
20	0·56	0·09	0·36	0·34	0·34	0·17
21	0·78	0·27	0·46	0·57	0·52	0·18
22	1·00	0·23	0·21	0·64	0·52	0·33
23	0·50	0·25	0·50	0·35	0·40	0·11
24	0·39	0·20	0·16	0·31	0·26	0·09
25	0·29	0·10	0·07	0·31	0·19	0·11
26	0·44	0·21	0·18	0·31	0·29	0·10
27	0·21	0·21	0·14	0·39	0·24	0·09
28	0·72	0·17	0·18	0·32	0·35	0·22
29	0·16	0·04	0·54	0·22	0·24	0·18
30	0·56	0·18	0·23	0·37	0·34	0·15
31	0·76	0·34	0·45	0·52	0·52	0·15
32	0·88	0·42	0·75	0·81	0·72	0·18
33	0·63	0·26	0·43	0·56	0·47	0·14

*Share of patents held by firms patenting for the first time in the period 1978–1986.

power plants, aircraft), because the index of innovative birth may be quite high even with a very limited number of new innovators. The information provided by NATALITY, SPEA and NEWLEADERS shed light on the degree of turbulence in each technological class: a high birth rate and low stability imply a high rate of turbulence, with new innovators emerging and a continuous change among innovators.

The four countries differ in terms of the relevance of new innovators (Table 4). The average value of NATALITY is highest in Italy (which is also the country with the lowest number of total patents) and is lowest in Germany (which is the country with the highest number of total patents). For this indicator, also, there is a striking similarity across countries (with the exception of the comparison between France and Italy) in the relevance of new innovators in each technological class and in the ranking of technological classes in terms of birth rates, as the Pearson and Sperman correlation indices (not reported here) show. The mechanical group and textiles have a relatively high rate of innovative birth in all the four countries, instruments a medium one, electronics and drugs a low rate, while the chemical group has different birth rates in the various classes (the majority of them, however, have low birth rates).

4. Schumpeterian patterns of innovation

The previous analysis has shown two further major general results. First, innovative activities are characterised by high degrees of concentration and stability in the hierarchy of major innovators and by the relevance of large firms in patenting activities. This result would seem to provide preliminary support to the Schumpeter Mark II model in the explanation of the patterns of innovation in contemporary advanced industrial economies.

Second, the various indicators of the patterns of innovative activities differ consistently across technological classes. These differences, related to the characteristics of the relevant technological régime, may discriminate among different patterns of innovative activity, some of which are closer to Schumpeter Mark I and some other are closer to Schumpeter Mark II.

In order to explore these differences, it is necessary (i) to examine what kind of relationships exist between the various indicators of the patterns of technological change supporting either of the two Schumpeterian models; and (ii) to identify groups of technological classes in which different but coherent relationships emerge between such variables. In particular *Schumpeter Mark II (deepening)* technological classes should be characterised by a high degree of concentration of innovative activities, systematically associated to high degrees of stability in the hierarchy of innovators, a high role of large firms and a low share of new innovators. However, unlike Schumpeter Mark II, *Schumpeter Mark I (widening)* should be characterised by a lower degree of concentration of innovative activities, systematically associated with a lower degree of stability in the hierarchy of innovators, a greater role for small firms and a higher share of new innovators.

4.1. Widening and deepening patterns of innovative activities

In order to explore empirically the relationships between various indicators of the patterns of innovative activity, a principal components analysis for all the technological classes in each country was performed (not reported here). This exercise generates in all the four countries one dominant factor which captures around 50% of the variance, and a second component which accounts for around 20–25% of the variance. These two factors clearly discriminate in all countries between the two groups of variables that characterise the two Schumpeterian patterns of innovative activities:

—indices of concentration and asymmetry, of the role of medium and large firms and of stability in the hierarchy of the persistent innovators
—indices of new innovators and new leaders.

More broadly, the empirical analysis identifies a more general dimension which could be broadly labelled as *stability*. High stability is defined by:

—low ease of innovative entry (NATALITY and NEWLEADERS)
—low change in the hierarchy of persistent innovators (SPEA).

Stability emerges as a very important feature of the patterns of innovative activities.

Patterns of innovative activity have been analysed at two different levels: macro technological families (mechanical, chemical and electronics) and 33 technological classes. At the *macro technological level*, major differences in the patterns of innovative activity can be found according to the widening and deepening models. Chemicals and electronics have the characteristics of the 'Schumpeter Mark II' model, whilst mechanical industries show a 'Schumpeter Mark I' model.

At the *technological class level*, it is indeed possible to define two groups of technological classes which can be labelled as Schumpeter Mark I and Schumpeter Mark II. In spite of the fact that some variability emerges in a cross-country analysis, technological classes systematically characterised in all four countries by a similar level of concentration and stability, and by a similar role of large firms and new innovators, have been identified. Two major groups of technological classes emerge (see Table 5). These groups have been confirmed by principal component analysis done for each country (not reported here).

A first group represents broadly *Schumpeter Mark I and the 'widening' pattern* of innovative activities: low concentration of innovative activities, symmetry among firms, instability in the ranking of innovators, high innovative birth-rates and many small innovative firms. It is composed of ten classes: non-metallic minerals, glass and other materials, food, metallurgical and other mineral processes, apparatus for chemicals, food and glass, general industrial equipment (non-electrical), non-electrical specialised and miscellaneous industrial equipment, metallurgical and metal-working equipment, assembling and material handling apparatus, other transport equipment (excluding aircraft), miscellaneous metal products and textiles, clothing, leather and wood products. In sum, this group includes the mechanical group and the 'traditional' industries.

A second group identifies the *Schumpeter Mark II and the deepening patterns* of innovative activities: high concentration and asymmetry among firms, stability in the hierarchy of innovators, low innovative birth-rate and relevance of large and medium-sized innovative firms. This group is composed of 14 classes: inorganic chemicals, organic chemicals, agricultural chemicals, hydrocarbons, mineral oils fuels and igniting devices, bleaching, dyeing and disinfecting, drugs and bio-affecting agents, plastics and rubber products, nuclear reactors and systems, power plants, road vehicles and engines, telecommunications, semiconductors, calculators, computers and other office equipment and photography and photocopying. That is to say, the Schumpeter Mark II model characterises most of the chemical and of the electrical-electronic industry.

The remaining technological classes do not fit neatly in any of the two previous groups. Two other small groups, however, are closer to Schumpeter Mark I classes than to Schumpeter Mark II ones. One has low concentration, high innovative birth-rate, but relatively large firm size. It includes chemical processes and general industrial apparatus (electrical). The other has low concentration, but low innovative birth-rates and mainly medium- and large-size firms. It includes electrical devices and systems and instruments and controls.

4.2. The role of stability in affecting international technological performance

One final question regards the possible relationship between specific variables which define the patterns of innovative activities and technological performance. This has been a long debated topic in the economics of technological change. Earlier results (Pavitt and Patel, 1991) have shown that no detectable relationship seems to exist between the 'traditional' Schumpeterian variables (such as concentration of the innovative activities and size of the innovative firms) and various measures of performance. Two reasons may explain this lack of a significant relationship. First, it may well be that such absence of correlation is due to the fact that the variables which may have an impact on international

Table 5. *Taxonomy of patterns of innovative activity*

(a) Schumpeter I: low concentration, low stability, high birth-rate, low firm size

—non-metallic minerals, glass and other materials
—metallurgical and other mineral processes
—apparatus for chemicals, food, glass etc.
—general industrial equipment (non-electrical)[a]
—non-electrical specialised and misc. industrial equipment
—metallurgical and metal working equipment
—assembling and material handling apparatus
—other transport equipment (excluded aircraft)
—miscellaneous metal products
—textile, clothing leather, wood products

(b) Low concentration, high birth-rate, high size[b]

—chemical processes
—general industrial apparatus (electrical)

(c) Schumpeter II: high concentration, high stability, low birth-rate, high firm size

—inorganic chemicals
—organic chemicals
—agricultural chemicals
—hydrocarbons, mineral oils, fuel, igniting devices
—bleaching, dyeing and disinfecting
—drugs and bio-affecting agents
—plastics and rubber products
—nuclear reactors and systems
—power plants
—road vehicles and engines
—telecommunications
—semiconductors
—calculators, computers, other office equipment
—photography and photocopying

(d) Low concentration, low birth-rate, high firm size

—electrical devices and systems
—instruments and control

(e) Other technological classes

—food and tobacco (processes and products)
—aircraft
—mining and well machinery and processes
—image and sound equipment
—other (ammunitions and weapons, road structure, bridges and plant and animal husbandry)

[a]The index of stability, SPEA, has a high value in two countries and the index of entry in the top ten innovators has a low value in three countries.

[b]The index of stability does not provide a uniform classification for all these classes with exception of aircraft and instruments.

technological performance are not the 'traditional' Schumpeterian variables related to concentration or size. Second, the relationship may be different in the two groups of technological classes (widening and deepening).

In order to assess these relationships for all technological classes, principal component analysis for all technological classes was performed introducing a measure of international specialisation in innovative activities: revealed technological advantages with respect to total world patents (RTA) and to the total patents held by the four countries considered (RTA4). RTA (RTA4) is the world (four countries) share of a country in a technological class over the world (four countries) share of that country in all technological classes. RTA (RTA4) greater than one shows specialisation of a country in a technological class, while RTA (RTA4) less than one shows despecialisation. The results from principal component analysis (not reported here) point to the important role played by the indicators of 'stability' in connection with performance, whilst the traditional variables such as concentration or size do not show any clear relationship with technological performance.

Exploratory regression analysis for all technological classes[1] with RTA4 as the dependent variable (see Table 6) confirms the significant role played by SPEA in affecting RTA4.[2] In this regression, standardised values (HERFS, SPEAS, SIZES and NATS) have also been used: they have been calculated by dividing each variable for the average value of each country. Stability emerges from regression analysis as the key factor affecting international technological specialisation and highlights the fact that 'creative accumulation' is a fundamental property of technological change: firms continuously active in a certain technological domain accumulate knowledge and expertise, and are able to master effectively and perform successfully in that technology.

4.3. *Schumpeterian patterns of innovation and international technological specialisation*

The second type of argument advanced previously (i.e. that the relationship between 'traditional' Schumpeterian variables and technological performance may be present but may be different in Schumpeter I and in Schumpeter II types of sector) has been discussed by examining only 22 Schumpeter I and II technological classes. Three key results emerge from regression analysis.

First, the introduction of a dummy variable *D* separating Schumpeter Mark I from Schumpeter Mark II classes in regression analysis (see Table 7) confirms that Schumpeter Mark I technological classes (with a dummy *D*) have specific and somewhat different effects on international technological performance (RTA4) compared to Schumpeter Mark II technological classes.

Second, exploratory regression analysis for Schumpeter Mark I and Schumpeter Mark II technological classes (see Tables 8 and 9) confirm the relevant role played by the 'stability' factor (in particular SPEA) both in the deepening and in the widening groups of technological classes.

Third, SIZE is significant but has a different coefficient sign in Schumpeter I (negative) and Schumpeter II (positive). This means that in widening patterns of

[1] Agricultural chemicals and nuclear reactors and systems, which fall in the Schumpeter Mark II group, have not been included in regression analyses concerning revealed technological advantages, because they are too small in terms of the absolute number of patents and might therefore bias the results.

[2] A spurious correlation exists between SIZE and RTA4 (the measure of international specialisation) since the same term, i.e. the number of patents of a given technological class, appears in the denominator of the first indicator and in the numerator of the second indicator. Similarly, in the relationship between NATALITY and RTA4 the number of patents of a given technological class in the period 1978–1986 appears in the denominator of the first indicator while it is included in the numerator of the second term (total number of patents in the period 1969–1986).

Table 6. *Factors affecting Revealed Technological Advantages (RTA4) of four countries: FRG, France, UK, Italy*

Dependent variable: RTA4 Independent variables	31 technological classes[a] Specifications		
INTERCEP	0·826***	0·782***	0·786***
	[0·192]	[0·177]	[0 176]
HERF	−0·014	−0·118	
	[0·275]	[0·291]	
SPEA	0·389***	0·393***	
	[0·093]	[0·091]	
SIZE	−0·014		
	[0·193]		
NAT	−0·027		
	[0·166]		
HERFS			0·012
			[0·027]
SPEAS			0·174***
			[0·042]
SIZES		0·0583	0·039
		[0·124]	[0·126]
NATS		−0·027	−0·008
		[0·071]	[0·072]
No. of observations	124	124	124
D.o.F.	123	123	123
R^2	0·143	0·147	0·145
Adj R^2	0·114	0·118	0·116
F value	4·968	5·111	5·025
Root MSE	0·257	0·257	0·257
Error mean square	0·066	0·066	0·066

[a]Agricultural chemicals (3) and nuclear reactors and systems (18) have been eliminated from our original sample of 33 technological classes.
HERFS = standardised value of HERFINDAHL (per country).
SPEAS = standardised value of SPEA (per country).
SIZES = standardised value of SIZE (per country).
NATS = standardised value of NATALITY (per country).
Numbers between square brackets indicate standard errors.
*Significant at the 10% level.
**Significant at the 5% level.
***Significant at the 1% level.

innovative activity an industrial structure characterised by innovators of smaller-sized is more conducive to satisfactory technological performance than a structure composed of larger-sized innovators. In deepening patterns of innovative activities an industrial structure characterised by innovators of larger size is more conducive to a satisfactory international technological performance than a structure composed of smaller firms. In a sense, the more a country has a structural feature that emphasises the 'right' dimension of the Schumpeterian pattern in terms of size, the better its international technological performance is.

Table 7. *Factors affecting Revealed Technological Advantages (RTA4) of four countries: FRG, France, UK, Italy*

Dependent variable: RTA4	22 technological classes		
Independent variables		Specifications	
INTERCEP	0·477*	0·43*	0·431*
	[0·282]	[0·253]	[0·249]
HERF	0·334	− 0·084	
	[0·354]	[0·363]	
SPEA	0·513***	0·381***	
	[0·134]	[0·119]	
SIZE	0·081		
	[0·277]		
NAT	0·587		
	[0·296]		
HERFS			0·009
			[0·035]
SPEAS			0·184
			[0·055]
SIZES		0·391**	0·356
		[0·178]	[0·178]
NATS		− 0·04	− 0·009
		[0·121]	[0·122]
DUMMY	0·892*	0·776	0·702
	[0·578]	[0·473]	[0·511]
DHERF	2·141	1·684	
	[3·3]	[3·118]	
DSPEA	− 0·125	− 0·015	
	[0·299]	[0·293]	
DSIZE	− 0·710		
	[0·549]		
DNAT	− 1·089**		
	[0·541]		
DHERFS			0·136
			[0·271]
DSPEAS			− 0·037
			[0·14]
DSIZES		− 0·779***	− 0·674**
		[0·323]	[0·345]
DNATS		− 0·036	− 0·028
		[0·203]	[0·204]
No of observations	88	88	88
D.o.F.	87	87	87
R^2	0·218	0·230	0·237
Adj. R^2	0·128	0·141	0·150
F value	2·417	2·586	2·701
Root MSE	0·253	0·251	0·250
Error mean square	0·064	0·063	0·063

HERFS = standardised value of HERFINDAHL (per country).
SPEAS = standardised value of SPEA (per country).
SIZES = standardised value of SIZE (per country).
NATS = standardised value of NATALITY (per country).
Numbers between square brackets indicate standard errors.
*Significant at the 10% level.
**Significant at the 5% level.
***Significant at the 1% level.

Table 8. *Factors affecting Revealed Technological Advantages (RTA4) of four countries: FRG, France, UK, Italy*

	Schumpeter Mark I (widening) technological classes 10 technological classes		
Dependent variable: RTA4			
Independent variables		Specifications	
INTERCEP	1·369***	1·206***	1·132***
	[0·384]	[0·304]	[0·346]
HERF	2·476	1·6	
	[2·5]	[2·36]	
SPEA	0·388**	0·365*	
	[0·204]	[0·204]	
SIZE	− 0·629**		
	[0·36]		
NAT	− 0·502		
	[0·346]		
HERFS			0·145
			[0·208]
SPEAS			0·147
			[0·1]
SIZES		− 0·389	− 0·318
		[0·205]	[0·23]
NATS		− 0·076	− 0·038
		[0·124]	[0·127]
No. of observations	40	40	40
D.o.F.	39	39	39
R^2	0·214	0·225	0·206
Adj. R^2	0·124	0·137	0·115
F value	2·385	2·545	2·272
Root MSE	0·193	0·192	0·194
Error mean square	0·037	0·037	0·038

HERFS=standardised value of HERFINDAHL (per country).
SPEAS=standardised value of SPEA (per country).
SIZES=standardised value of SIZE (per country).
NATS=standardised value of NATALITY (per country).
Numbers between square brackets indicate standard errors.
*Significant at the 10% level.
**Significant at the 5% level.
***Significant at the 1% level.

5. Conclusions

This paper has demonstrated the following:

(i) Patterns of innovative activities differ systematically across technological classes.

(ii) Remarkable similarities emerge across countries in the patterns of innovative activities for each technological class. This result suggests strongly that 'technological imperatives' and technology-specific factors (closely linked to technological régimes) play a major role in determining the patterns of innovative activities across countries.

(iii) It is possible to define two groups of technological classes in which innovative activities are organised according to the Schumpeter Mark I and the Schumpeter Mark

Table 9. *Factors affecting Revealed Technological Advantages (RTA4) of four countries: FRG, France, UK, Italy*

Dependent variable: RTA4 Independent variables	Schumpeter Mark II (deepening) technological classes 12 technological classes Specifications		
INTERCEP	0·477 [0·327]	0·430 [0·293]	0·431 [0·286]
HERF	0·334 [0·41]	−0·084 [0·42]	
SPEA	0·513*** [0·156]	0·381*** [0·138]	
SIZE	0·081 [0·321]		
NAT	0·587* [0·343]		
HERFS			0·009 [0·04]
SPEAS			0·184*** [0·063]
SIZES		0·391* [0·207]	0·356* [0·205]
NATS		−0·04 [0·14]	−0·009 [0·14]
No. of observations	48	48	48
D.o.F.	47	47	47
R^2	0·215	0·227	0·245
Adj. R^2	0·142	0·155	0·174
F Value	2·952	3·164	3·484
Root MSE	0·294	0·291	0·288
Error mean square	0·086	0·085	0·083

HERFS = standardised value of HERFINDAHL (per country).
SPEAS = standardised value of SPEA (per country).
SIZES = standardised value of SIZE (per country).
NATS = standardised value of NATALITY (per country).
Numbers between square brackets indicate standard errors.
*Significant at the 10% level.
**Significant at the 5% level.
***Significant at the 1% level.

II models. The first represents a 'widening' pattern and the second a 'deepening' pattern of innovative activities. The former group comprises the mechanical and the traditional sectors; the latter comprises chemicals and the electrical-electronic industries. Other technological classes show an intermediate behaviour, as a consequence of the specific features of the relevant technological regime.

(iv) Each of the two groups emphasises specific variables that affect international technological performance. In Schumpeter Mark I technological classes an industrial structure in which innovators are of small size is more conducive to technological performance than an industrial structure in which innovators are of larger size. The opposite is true in Schumpeter Mark II technology classes.

(v) An additional dimension—'stability'—emerges as an important feature of the patterns of innovative activity: technological performance is strongly associated with the emergence of a stable group of innovators, who innovate consistently and continuously over time, rather than to concentration or firm size. This result holds both in deepening and in widening technological classes.

This last result concerning the effect of stability on performance opens up several important theoretical questions and policy issues and calls for further research. From the theoretical point of view, it confirms the cumulative nature of technological change and vindicates the Schumpeterian insight that the patterns of innovative activities are to be analysed in an explicitly dynamic contect. As far as policy is concerned, the implications are that a primary focus of government action should be on creating, strengthening and widening a core group of consistent and continuous innovators, as a necessary complement to actions directed towards the support to innovation in new, small firms.

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Appendix

List of the 33 technological classes

1 Inorganic chemicals
2 Organic chemicals
3 Agricultural chemicals
4 Chemical processes
5 Hydrocarbons, mineral oils, fuel, igniting devices
6 Bleaching, dyeing and disinfecting
7 Drugs and bio-affecting agents
8 Plastics and rubber products
9 Non-metallic minerals, glass and other materials
10 Food and tobacco (processes and products)
11 Metallurgical and other mineral processes
12 Apparatus for chemicals, food, glass etc.
13 General industrial equipment (non-electrical)
14 General industrial apparatus (electrical)
15 Non-electrical specialised and misc. industrial equipment
16 Metallurgical and metal working equipment
17 Assembling and material handling apparatus
18 Nuclear reactors and systems
19 Power plants
20 Road vehicles and engines
21 Other transport equipment (excluding aircraft)
22 Aircraft
23 Mining and well machinery and processes
24 Telecommunications
25 Semiconductors
26 Electrical devices and systems
27 Calculators, computers, other office equipment
28 Image and sound equipment
29 Photography and photocopying
30 Instruments and controls
31 Miscellaneous metal products
32 Textile, clothing, leather and wood products
33 Other (ammunitions and weapons, road structures, bridges and plant and animal husbandry)