Diversification and Specialisation in Innovative Activities:

An Analysis of Patenting Activity of Electronic Firms

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***Abstract*:**
This paper has shed light on the processes of technological diversification and specialization by firms. European, American and Japanese firms have been examined in 25 technological fields within telecommunications, information and audiovisual technologies for the period 1978-1998. In general, in electronics technologies incumbent firms are engaged in continuous processes of technological diversfication, opening up windows on new technologies. On the contrary new innovators tend to start highly specialized and most of them remain so. From this analysis an explanation of the European weaknesses in electronics technologies based on the weaknesses of both the core and the fringe of European innovators emerges. As far as the core is concerned, in electronics Europe does not have a big core of numerous large competent companies that span over mature as well as new technologies. In this way, big projects on broad technologies, the continuous opening of windows on new technologies and the pursue of multitechnology initiatives that requite the integration of different complementary technologies may be unpaired. As far as the fringe of innovators is concerned, Europe is characterized by a too high entry of small firms specialised in mature technologies. The problem here is not entry but survival. Most of the new innovators are not able to become continuous innovators and do not survive as innovators for long. Even those that survive are unable to widen their specialisation, and move from mature to emerging technological fields.

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1. Introduction

This paper examines the patterns of technological diversification and specialization in telecommunications, information and audiovisual technologies by European, American and Japanese firms in the period 1978-98.

Over time large and small firms engaged in continuous innovative activities learn and accumulate knowledge. These firms may end up specialising in specific technologies and knowledge domains. On the contrary they may open up windows on new technologies or enter into technologies that are complementary, or closely related in terms of knowledge or subject to spillover effects.

The first process is a *focusing process*, since it involves an increasing focus on fewer technologies. The second process is a *widening process*, since it is associated to a growing number of technologies mastered by firms. A focusing process may imply a growing specialisation of innovative activities, while a widening process leads to multitechnology firms. These two patterns may be related to different hypotheses on the type of knowledge, the kinds of firms and the interaction processes that characterize innovative activities. The dissussion about these issues is outside the scope of the present paper (Granstrand, 1997; Arora-Gambardella, 1994; Granstrand, Patel and Pavitt, 1997).

The starting point of our analysis is the remark that persistence of innovative activities, widely examined by several contributions (Malerba-Orsenigo-Peretto, 1997; Geroski-Van Reenen-Walters, 1997; Cefis, 1996), is usually coupled with technological diversification. However, the analyses of persistence just mentioned have not linked persistence with the presence of firms in more than one technology. On the other hand, technological diversification (see Patel and Pavitt and Piscitello in this project) has not been associated with the persistence of firms in innovative activities.

This project aims at linking these two issues (persistence and diversification vs. specialisation) by examining the processes of technological widening or focusing by continuous innovators.

Our analysis aims to answer the following questions:

- First, do persistent innovators *widen* their technological activities over time? In other words, does firms' technological learning process lead to new technologies and thus to expand the range of technologies they master? This may be so either because spillover effects (knowledge proximity) and complementarities may be present or because persistent innovators are engaged in continuous search, aiming to diversify and open windows into new technologies in order to maintain their innovation rates high in the face of diminishing returns in their current activities. Or would we expect that continuous technological activities imply a *focusing* process by which firms abandon technologies that are not core anymore and increasingly concentrate on some key technologies? In this case we would therefore expect an increasing technological specialisation. One reason for the focusing process would be the increasing focus on core capabilities and technologies and the disregard for technologies that are not relevant for firms' core activites (Prahalad-Hamel, 1991). Another would be the increasing use of information technology and instrumentation that would allow firms to become increasingly technologically specialised and to exchange knowledge and information about other technologies (Arora-Gambardella, 1994).

- Second, do *new innovators* start technologically specialized or technologically diversified? In other words, when they start their innovative activities, do entrants have to master few technologies or a wide range of them?
- Third, how could we characterize the process of technological learning and technological widening by *small firms*? Do small firms remain highly specialized or do they widen their activities over time?
- Fourth, do we expect major differences *among technologies* in the focusing and widening patterns? And for the same technology, do these patterns *hold across countries*? From the literature on technological regimes and Schumpeterian patterns of innovation (Malerba-Orsenigo, 1995, 1997) we would expect that for the same technology similar patterns exist across countries.
- Fifth, should we expect that the specificities of the *national systems of innovation* of various countries affect the extent of widening and focusing processes in a given technology?
- And finally, are we able to identify some of the *main determinants* of the widening or focusing processes? Are these processes related to the age and size of firms?

The paper is organised as follows. In Section 2 we will review what we know about technological diversification. Section 3 describes the sources of data and the process of sample selection and data set building. Section 4 provides some stylised facts about technological entry, while section 5 examines the extent and the evolution of technological diversification of electronic firms. Section 6 examines patterns of technological diversification by building a measure of technological relatedness, and section 7 the relationship between firms' patterns of diversification and the degree of maturity (age) of technologies. Section 8 provides a synthesis and some concluding remarks.

2. What do we know about technological diversification?

Previous analyses on firms' innovative activities have found that a lot of technological learning, competence accumulation and technological diversification takes place among persistent innovators. The contributions by Pavitt et al. (1989), Patel and Pavitt (1995), Pavitt (1997), Granstrand (1997), Granstrand and Sjölander (1990), Oskarsson (1993), Cantwell and Andersen (1996) among others have highlighted some key points. First, in high technology or technology based industries technological diversification is usually greater than product diversification. Firms are quite broad in terms of knowledge and have to manage a wide number of technologies in order to develop and produce products and services. Thus most firms could be labelled multitechnology corporations even if they are specialised in one line of business (Granstrand, 1997). Second, most of the time technological diversification anticipates product and market diversification (Pavitt, 1997). This is so because technological exploration in a wide range of technologies is a prerequisite for production. Third, the profile of technological diversification of firms is rather stable. It changes slowly over time as a consequence of the inertia of specialisation, incremental changes in knowledge production and modifications in firms competences (Patel and Pavitt, 1995; Cantwell and Andersen, 1996). Fourth, the profile of technological diversification differs across large firms, as a consequence of the history of the corporations, initial conditions, the specialisation of the companies, the market incentives and the specific institutional setting in which companies are embedded. However, the profile of technological diversification is very similar among large firms producing similar products, particularly in high technology and technology based industries. These results have shed light on some important features of technological diversification. Their conclusions however are based on specific detailed case studies (Granstrand, 1997; Granstrand-Sjolander, 1990) or on quantitative analyses of the world largest corporations based on patent indicators.

In a previous paper (Breschi-Lissoni-Malerba, 1999) we have examined persistence and technological diversification in patenting activity for the whole population of innovators in six advanced countries. We have found confirmation that persistent innovators are highly important in terms of patents even though they represent a minor part of the whole population of innovative firms. Thus, there is a distinction to be made here between firms and innovations (patents): in terms of firms, persistent innovators are a relatively minor part of all patenting firms, while in terms of patents persistent innovators are quite important. In our previous analysis, we found that the importance of persistent innovators differs strongly among countries. Germany and Japan appear as the most persistent countries (both in terms of patents and firms), while Italy and the UK the less persistent ones. In the first two countries, innovative activities show high degrees of continuity (more than 80% of all patents are held in Japan by firms that innovate continuously, and in Germany the situation is similar), while in Italy and the UK only around 50% and 60%, respectively, of all patents are applied for by persistent innovators.

The large majority of persistent innovators is composed by technologically diversified firms: the share of technologically diversified firms among persistent innovators is considerably high. In all countries examined, technologically diversified firms represent more than 90% of all persistent innovators. Also in terms of patents, diversified innovators account for a share of around 50-65% of all patents held by persistent innovators. These preliminary results suggest therefore that being technologically diversified (i.e. being able to master and use different technologies) represent a necessary requisite to survive in the long run as an innovator (and possibly also as a manufacturer).

Most small diversified innovators are present in just two technological classes (50% of all technologically diversified firms). Around 20% are present in just three. At the same time, firms diversified in two technological classes hold only around 7.5% of total patents held by technologically diversified firms in the period 1982-93, while firms active in three technological classes hold slightly less than 4.5% of all patents in the same period. These results taken together suggest that while most diversified firms are present in a relatively low number of technological fields (e.g. slightly more than 70% and 80% of them hold patents in less than four and five technological classes, respectively), they are also small innovators (e.g. only around 12% and 17% of all patents by diversified firms are accounted for by firms diversified in less than four and less than five technological classes, respectively).

Very few firms are diversified in most technological fields, but they are very large innovators (e.g. only 6 firms patented in all 30 technological classes in the period 1982-93 and only 7 patented in 29 classes). Firms diversified in more than 24 technological fields are only 70 (or less than 1% of all diversified firms), but they are responsible for almost 30% of all patents filed at EPO in the period 1982-93).

Summing up, we can conclude that technological diversification is a widespread phenomenon in Europe, the United States and Japan. Generally speaking, only occasional innovators are not technologically diversified. On the contrary, most persistent innovators are diversified in at least two technologies. This implies that most firms have to master and integrate different technologies in their products and processes in order to survive as innovators (and possibly also as manufacturers).

In Breschi-Lissoni-Malerba (1999) we also found also that firms diversify along certain directions which reflect the working of local search, spillover, linkages and complementarities and proximity mechanisms. Using 30 technological classes covering all IPC, we found four major clusters of technologies in which firms are diversified: chemicals and bio-pharmaceuticals, materials, mechanical and process technologies, and electrical and electronic technologies. Moreover these clusters have been rather stable in terms of composition and technological distances over the last 15 years. No major differences among countries are present. Technological spillover, linkages and proximity has been shown to be an important factor in the process of technological diversification: established innovators enter technologies that are close to the ones in which they are currently involved.

Our previous analysis however is not focused on the processes of expansions or contraction of innovative activities by firms. This is the scope of the present paper.

3. Data sources

This paper uses patent applications to the European Patent Office (EPO), since 1978 (the foundation year of EPO) to 1998, by firms coming from US, Japan, Germany, France, Italy and the UK. For any patent application included in the EPO database, we have extracted information on applicant's name and address, date of application, main and secondary technological class. Patents have been aggregated into 30 technological classes following the classification of the International Patent Classification (IPC) codes proposed by OST (Paris), INPI (Paris) and FhG-ISI (Karlsruhe).[1]

From this data set, we extracted the sample of all patents classified into three technological classes, i.e. Audiovisual technology, Telecommunications and Information technology. The three technological macroclasses have been further divided into 25 technological microclasses (see Table A1 - Appendix) following the breakdown proposed by FhG-ISI (Schmoch, 1994). From all firms patenting in the 25 technological microclasses, we have then selected those firms active in one (or more) of four US 3-digits SIC codes: i) Computer office equipment (357); ii) Household radio and video equipment and audio recording (365); iii) Communication equipment (366); iv) Electronic components and accessories (367). The sample thus selected includes 621 firms and 30,534 patent applications. For each of the 621 firms included in the sample, economic data have been finally collected using various business databases on CD-R: *Diane* (for France), *Markus* (for Germany), *Aida* (for Italy), *Fame* (for the UK), *Jade* (for

[1] In addition to measuring innovation (with all the strengths and weaknesses and the methodological problems associated to this, see Griliches, 1991), patent applications are very good indicators of firms' technological competences and reflect firms' knowledge. The fact that firms apply for a patent in a given technology means that firms are at, or close to, the technological frontier and have advanced technological competences. Thus, a patent application by a firm in a specific technology means that that firm has advanced knowledge in that technology. However, competences and knowledge as reflected in patent applications do not necessarily imply that patents will turn out to be innovations in the market (as it has been rightly observed by several critics of patents as indicators of innovation). Rather, patents indicate the presence of technological competences of a firm in a specific technological field.

Japan) and *Corporate America* (for US). For each of the 621 firms in the sample, the following economic information are available: a) date of foundation (some missing values); b) number of employees (various years with missing values); c) US SIC codes; d) sales (various years with missing values). Overall, the sample selected accounts for about 35% of all patent applications classified in the 25 technological microlasses in the period 1978-1998 and it contains 127 firms and 5084 patents for Germany, 66 firms and 2341 patents for France, 34 firms and 633 patents for Italy, 136 firms and 16116 patents for Japan, 57 firms and 82 patents for the UK, and 201 firms and 6178 patents for the United States.

4. Technological entry

Since the main interest of this paper is on the processes of technological specialisation vs. diversification of electronic companies during the 90's, we have divided the observation period 1978-1998 into three subperiods: 1978-1985, 1986-1991, 1992-1998. The choice of these intervals has been dictated by the following considerations. The European Patent Office (EPO) has been founded in 1978 and many firms, especially small ones, needed a 'learning' period before starting to patent to the EPO. In other terms, observing no patenting activity in the first years after the EPO establishment does not necessarily imply that the firm was not active in a certain technological field. We have therefore kept this 'learning' period sufficiently long (8 years) to allow for this type of effect. The second subperiod is intended to capture the process of technological entry of firms not active during the first half of the 80's, while the third subperiod is meant to record the second wave of technological entry that has occurred during the first half of the '90s.

On this basis, it is possible to distinguish four types of patenting firms which are relevant for our analysis:

- *First cohoort of entrants technologically discontinuous*: these are firms that patented in the period 1978-85, interrupted their patenting activity in the period 1986-91, and resumed it in the period 1992-98 (INSTAB);
- *Second cohoort of entrants technologically active*: these are firms that started to patent in any of the 25 technological microclasses in the period 1986-91 and and are still technologically active in the period 1992-98 (SECOIN);
- *Third cohoort of entrants*: these are firms that started to patent in any of the 25 technological microclasses in the period 1992-98 (THIRDIN);

- *Persistent innovators*: these are firms that patented in any of the 25 technological microclasses in the period 1978-85 and kept on patenting both in period 1986-91 and in period 1992-98 (PERSIST).

Using the categorisation of patenting firms proposed above, we will first analyse the extent and importance of processes of technological entry for each technological microclass, and secondly we will examine for each category of patenting firms the extent to which a process of technological diversification or specialisation has taken place over time, using a commonly adopted indicator like the Herfindahl index.

Looking at the overall process of technological entry, the evidence shows that firms starting to patent in the period 1992-98 (THIRDIN) account for the largest share of all patenting firms in the same time interval (Table 1). However, in terms of patents, persistent innovators are a far more important source of innovative activity holding a share of total patent applications above 83%. It is also worth observing that discontinuous innovators (INSTAB) account for a very low share of both patenting firms and patents, thus supporting the idea that the probability to resume patenting after a ‘long’ period of technological inactivity is very low.

Considerable differences in the role of technological entrants vs. persistent innovators emerge when considering specific countries (Table 2). In particular, in Germany, US and Japan persistent innovators (PERSIST) and the second cohoort of entrants still active (SECOIN) account for a larger share of all patenting firms and patents compared to the other European countries. Moreover, for US the second cohoort of entrants still active (SECOIN) account for quite a large share of all patent applications in the period 1992-98 (26.3%). Among the European countries, only Germany presents a comparable share of patents held by this category of firms. With the only exception of the UK, for which the available data do not allow us to draw safe results, European countries present a considerable degree of dynamism in terms of technological entry of new patenting firms. However, such firms are more likely to enter with a relatively low number of patents and in a less persistent fashion, particularly compared to the US.

Beyond this pooled analysis, it is also useful to examine the process of technological entry for each of the 25 microclasses considered here, looking at the period 1992-98. To this purpose, patenting firms can be divided into three main categories for the sake of simplicity:

- *Persistent innovators*: firms that were patenting in microclass *j* either in the period 1978-85 or in the period 1986-91 or in both subperiods and keep on patenting in microclass *j* in the period 1992-98.

- *Lateral entrants*: firms that were not patenting in microclass *j* both in the period 1978-85 and in the period 1986-91, but were patenting in some other technological microclass $i \neq j$ and start patenting in microclass *j* in the period 1992-98.
- *Net entrants*: firms that were not patenting in microclass *j* both in the period 1978-85 and in the period 1986-91 and start patenting in microclass *j* in the period 1992-98.

Results are reported in Tables 3 and 4, respectively, for the six countries pooled together and for each country separately. Looking at the pooled results, it emerges quite clearly the existence of differences across technological microclasses in the importance of lateral and net entrants vs. persistent innovators as sources of innovation. This may imply that within broad families of technologies (i.e. telecommunications, audiovisual technologies and information technology) different technologies coexist characterised by different technological regimes. Net entrants are relatively important in the following microclasses: coding and decoding (1), data recognition and presentation (6), broadcast systems (17), microphones (19), pulse techniques (21), secret communication (22), transmission of measured values (23), aerials (24). Lateral entrants (i.e. technological diversifying companies) have a relatively high share of patents in the following microclasses: speech analysis (5), optical computing (9), telephones (9), broadcast systems (17), microphones (19), secret communication (22), aerials (24) and error detection (25).

Table 1

The role of technological entry, all microclasses, 1992-98

Category	No. of firms	% of firms	No. of patents	% of patents
PERSIST	81	17.15	12432	83.59
SECOIN	87	18.20	1557	10.46
THIRDIN	300	62.76	831	5.58
INSTAB	9	1.88	52	0.34
Total	*478*	*100*	*100*	*100*

Table 2

The role of technological entry, all microclasses, six countries, 1992-98

	France		Germany		UK		Italy		Japan		US	
Category	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
PERSIST	15	17.2	7	13.5	-	-	1	4.0	25	21.4	33	21.2
SECOIN	10	11.5	9	17.3	3	7.3	5	20.0	27	23.1	33	21.2
THIRDIN	59	67.8	35	67.3	37	90.2	19	76.0	63	53.8	88	56.4
INSTAB	3	3.4	1	1.9	1	2.4			2	1.7	2	1.3
Total	*87*	*100*	*52*	*100*	*41*	*100*	*25*	*100*	*117*	*100*	*156*	*100*
	(c)	(d)	(c)	(d)	(c)	(d)	(c)	(d)	(c)	(d)	(c)	(d)
PERSIST	1693	90.8	709	65.9	-	-	395	86.2	7413	93.6	2222	65.0
SECOIN	61	3.3	246	22.9	6	4.4	36	7.9	311	3.9	897	26.3
THIRDIN	103	5.5	120	11.2	129	94.9	27	5.9	170	2.1	282	8.3
INSTAB	8	0.4	1	0.1	1	0.7	-	-	27	0.3	15	0.4
Total	*1865*	*100*	*1076*	*100*	*136*	*100*	*458*	*100*	*7921*	*100*	*3416*	*100*

Note: (a) No. of firms; (b) % of firms; (c) No. of patents; (d) % of patents.

Across countries both similarities and differences in the relative importance of entrants vs. persistent innovators seem to emerge (Table 4). In all countries considered here, new innovators account for a relatively large share of patents in the following microclasses: broadcast systems (17), TV sets and cameras (19), pulse techniques (21), secret communication (22), transmission of measured values (23) and aerials (24). However, correlation coefficients across countries among the vectors corresponding to the share of net and lateral entrants, although statistically significant, do not present particularly high values, therefore indicating important differences among national systems of innovation. In particular, it is quite striking the difference between Japan and Germany, on the one hand, and US, on the other hand. While Japan and Germany are in fact characterised by a strong role played by incumbent innovators, US seems to exhibit a

Table 3

Share of patents held by peristent innovators, lateral entrants and net entrants
25 technological microclasses, six countries, 1992-98

	Persistent Innovators	*Lateral Entrants*	*Net Entrants*	*Total*
1.Coding decoding	74.29	-	25.71	100
2 Displays	88.14	5.35	6.51	100
3. Stores with relative movement	92.34	2.55	5.10	100
4. Solid body stores	90.10	6.48	3.42	100
5. Speech analysis	87.44	12.56		100
6. Data recognition and presentation	85.60	5.16	9.23	100
7. Data input and output	87.19	6.05	6.76	100
8. Electrical data processing	90.39	4.05	5.56	100
9. Optical computing	45.45	54.55	-	100
10. Switching	87.40	6.97	5.62	100
11. Electrical transmission	87.24	9.08	3.68	100
12. Radio transmission	85.00	8.93	6.07	100
13. Optical transmission	87.55	6.83	5.62	100
14. Telephones	79.25	16.04	4.72	100
15. Fax terminals	94.32	1.78	3.90	100
16. TV systems	88.17	9.30	2.54	100
17. Broadcast systems	65.88	20.00	14.12	100
18. TV sets and camera	92.77	2.62	4.61	100
19. Microphones. Loud speakers. Stereo	62.62	21.96	15.42	100
20 Amplifiers. Tuners. Oscillators	88.85	5.08	6.07	100
21. Pulse technique	83.23	5.67	11.10	100
22. Secret communication	48.05	36.36	15.58	100
23. Transmission of measured values	58.70	10.87	30.43	100
24. Aerials	57.24	27.93	14.83	100
25. Error detection and transm. control	68.09	26.81	5.11	100

higher degree of dynamism in terms of entry of new and lateral innovators in almost all technological microclasses. New innovators play an important role in several classes also in the case of France, while Italy presents a peculiar behaviour (also because of the very low number of patents) with persistent innovators dominating some key technologies and with new (net and lateral) entrants accounting for all patents in other technological microclasses.

Table 4

Share of patents held by peristent innovators, lateral entrants and net entrants by country, 25 technologi

	P	*L*	*N*	*P*	*L*	*N*	*P*	*L*	*N*	
	Germany			*France*			*Italy*			
1.Coding decoding				66.7		33.3				
2 Displays	82.1	5.1	12.8	46.2		53.8		50.0	50.0	93
3. Stores with relative movement	80.0		20.0	62.1		37.9	35.7	57.1	7.1	96
4. Solid body stores	95.7	4.3		95.0	3.3	1.7	100.0			93
5. Speech analysis	100.0			41.2	58.8					99
6. Data recognition and presentation	81.5	2.5	16.0	58.0	6.0	36.0		80.0	20.0	91
7. Data input and output	66.7	11.1	22.2	81.8	9.1	9.1				94
8. Electrical data processing	96.9	1.0	2.1	96.3	0.7	2.9	90.0	8.3	1.7	95
9. Optical computing	100.0			100.0						10
10. Switching	96.5	0.9	2.6	80.6	13.9	5.6	100.0			96
11. Electrical transmission	95.0	3.9	1.1	92.5	2.8	4.7	66.7	33.3		93
12. Radio transmission	87.1	9.1	3.8	94.3	2.9	2.9		25.0	75.0	95
13. Optical transmission	89.2	9.2	1.5	68.6	2.9	28.6				93
14. Telephones	84.0	10.7	5.3	35.7	50.0	14.3		100.0		96
15. Fax terminals	63.6	13.6	22.7	25.0	75.0			100.0		96
16. TV systems	91.8	3.3	4.9	61.2	32.7	6.1		100.0		97
17. Broadcast systems	70.6	17.6	11.8	66.7	16.7	16.7		100.0		71
18. TV sets and camera	75.0		25.0	85.3	2.9	11.8	81.8		18.2	96
19. Microphones. loud speakers. Stereo	94.4	3.7	1.9		63.6	36.4		50.0	50.0	61
20 Amplifiers. tuners. Oscillators	87.8	4.9	7.3	90.5	1.2	8.3	95.9	2.0	2.0	92
21. Pulse technique	91.2	4.4	4.4	74.6		25.4	97.8	2.2		86
22. Secret communication	93.8	6.3		62.5	12.5	25.0				45
23. Transmission of measured values	50.0		50.0	66.7	33.3				100.0	40
24. Aerials	72.0	14.0	14.0	83.1	13.8	3.1	23.1		76.9	41
25. Error detection and transm. control	90.6	6.3	3.1	40.0	57.1	2.9			100.0	83

Note: P = persistent innovators; L = lateral entrants; N = net entrants. UK not reported because of a too low number of pate

5. Extent and evolution of technological diversification

This section examines the extent and the evolution over time of technological diversification of electronic firms. With regard to the first aspect, Chart 1 reports the distribution of firms and patents in our sample according to the number of technological fields in which firms have been active over the period 1978-1998. The chart shows that the great majority of firms (more than 60%) patent in only one the 25 technological classes. Moreover, firms patenting in less than 5 technological fields account for slightly more than 80% of all firms in our sample, indicating that most electronic firms are either extremely specialised or diversified in few fields. At the same time, the chart also indicate that the most diversified firms are also the largest innovators. Firms active in more than 22 fields account for almost 45% of all patents produced by firms in the sample. It is worth noting that this value is considerably higher than the one observed with respect to all technological classes (Breschi, Lissoni and Malerba, 1998). Finally, persistent innovators represent 32% of all diversified firms, but they account for slightly more than 90% of all patents by diversified firms in our sample.

A central question to our present analysis is the extent to which electronic firms have undertaken processes of technological specialisation over time, particularly during the '90s. To this end, we have calculated the Herfindahl index across the 25 technological microclasses for each category of patenting firms defined above. Since the Herfindahl index can take values ranging from 0.04 to 1, firms have been split into five frequency intervals: highly diversified ($0.04 \leq HH < 0.232$: HDIV), fairly diversified ($0.232 \leq HH < 0.424$: DIV), medium diversified ($0.424 \leq HH < 0.616$: MDIV), fairly specialised ($0.616 \leq HH < 0.808$: SPEC), highly specialised ($0.808 \leq HH < 1$: HSPEC).

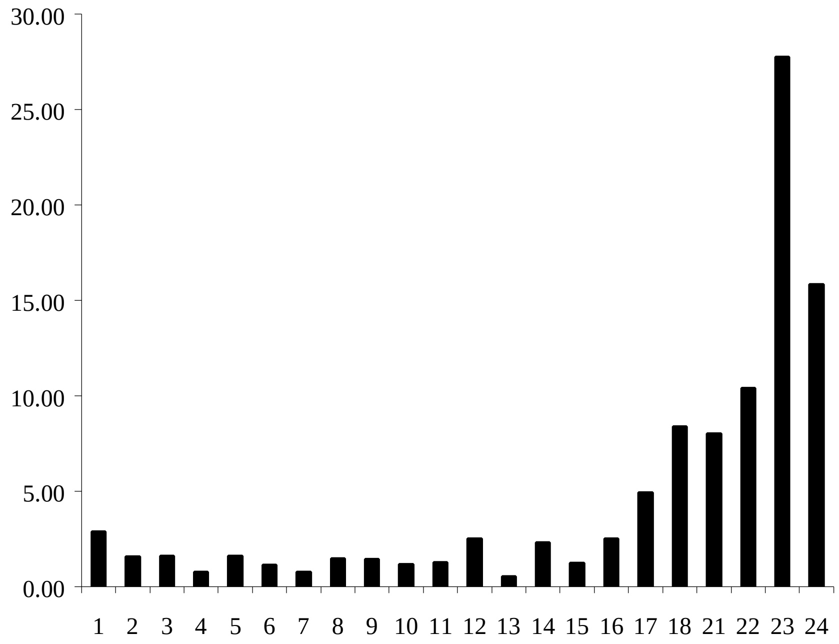
Chart 2 reports the distribution of persistent patenting firms (PERSIST) according to the degree of technological diversification over time. It emerges quite clearly that going from the first subperiod 1978-85 to the second period 1986-91, the distribution shifts to the left, with a sharp reduction in the share of highly specialised firms (HSPEC) and a corresponding increase of the fairly diversified (DIV) and the highly diversified (HDIV) firms. Incumbent innovators have started their innovative activity in few technological classes and have gradually diversified over the '80s into other technologies. However, this process of gradual technological diversification seems to fade during the '90s. The share of highly specialised firms (HSPEC) increases from about 19% to 23% between the period 1986-91 and the period 1992-98. Beside that, however, the share of highly diversified firms also increases from about 24% in the period 1986-91 to about 27% in the period 1992-98. Generally speaking, the distribution of persistent innovators according to the degree of technological diversification appears to be much more uniform during the ‘90s compared to the ‘80s, with a fairly equal share of diversified and specialised companies.

Concerning the second cohoort of innovative firms (SECOIN), Chart 3 shows that, in general, these companies have started their patenting activity in a very narrow number of technological classes. As for the persistent innovators, also in this case one observes a shift of the distribution to the left witnessing a process of technological diversification during the ‘90s. However, the trend towards technological diversification appears less strong than for the group of persistent innovators. Highly specialised firms still account for 40% of all patenting firms in this category.

Figure 1 plots the Herfindahl indexes in the periods 1986-91 and 1992-98, respectively, for persistent firms (PERSIST) and for the second cohoort of innovators (SECOIN). The plot allows us to appreciate for quite a high number of persistent innovators a trend towards increasing technological diversification. Conversely, the second cohoort of entrants exhibits either stable or increasing levels of technological specialisation.

Chart 1 – Distribution of firms and patents according to the number of technological fields in which they are active, 1978-1998

(a) Patents



(b) Firms

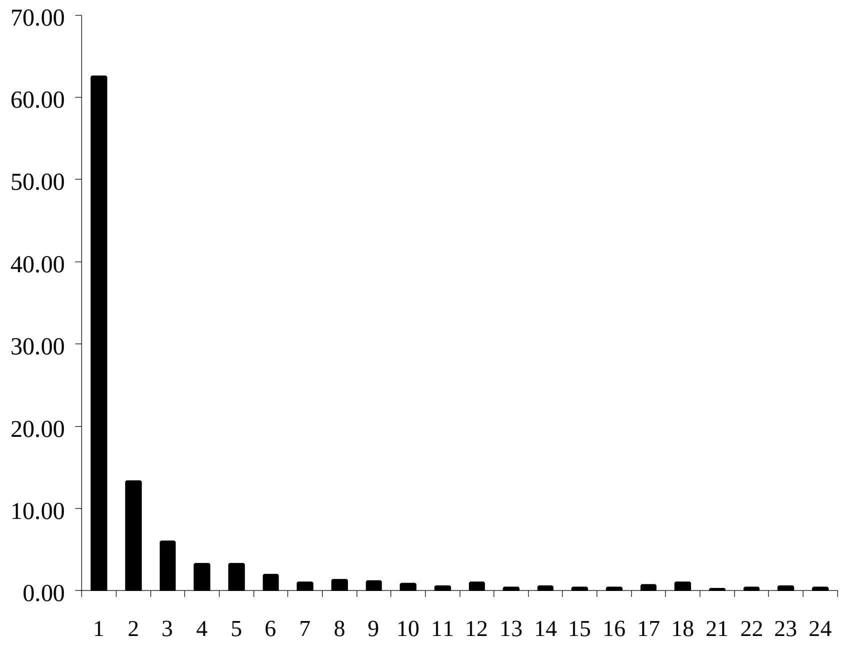
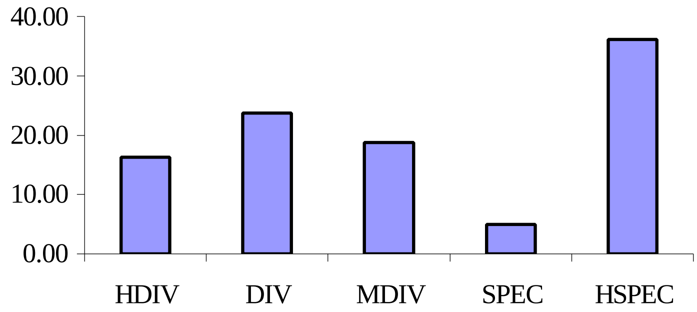


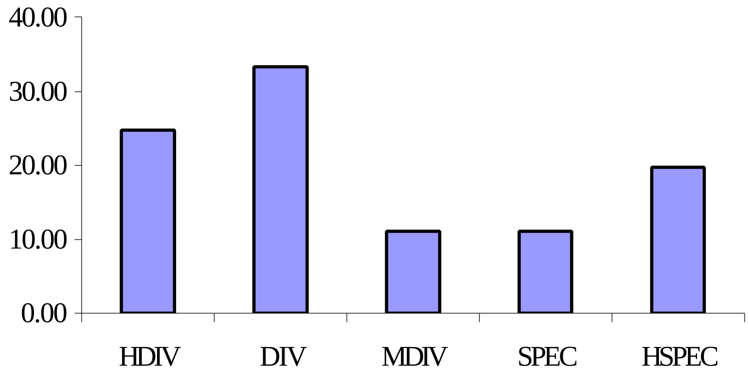
Chart 2

Distribution of persistent innovators (PERSIST) by degree of technological diversification (Herfindahl index , n=81, %)

1978-85



1986-91



1992-98

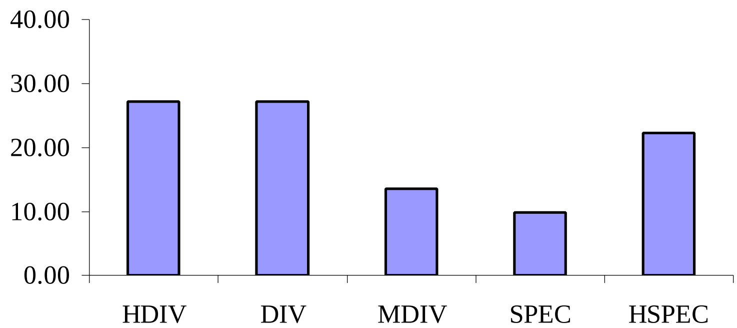
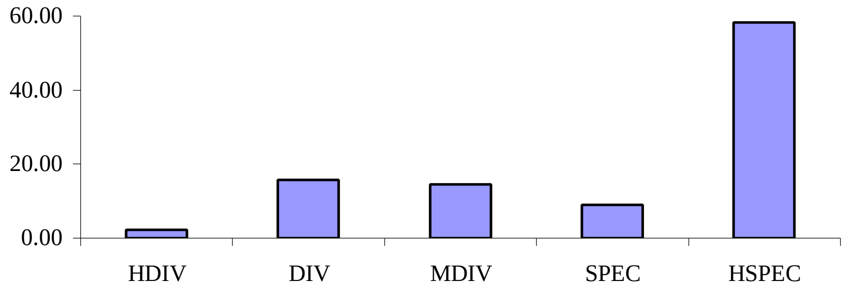


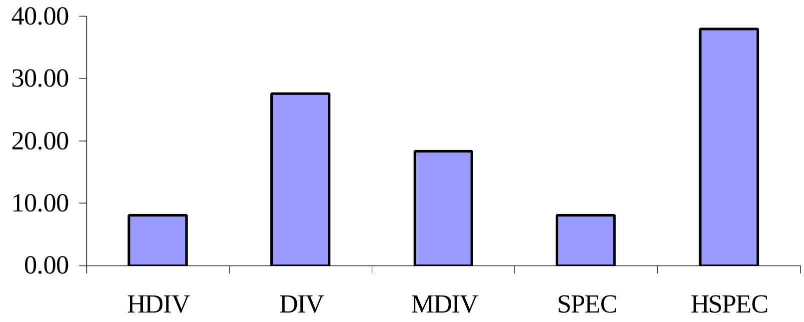
Chart 3

Distribution of second cohoort patenting firms (SECOIN) by degree of technological diversification (Herfindahl index , n=87, %)

1986-91



1992-98

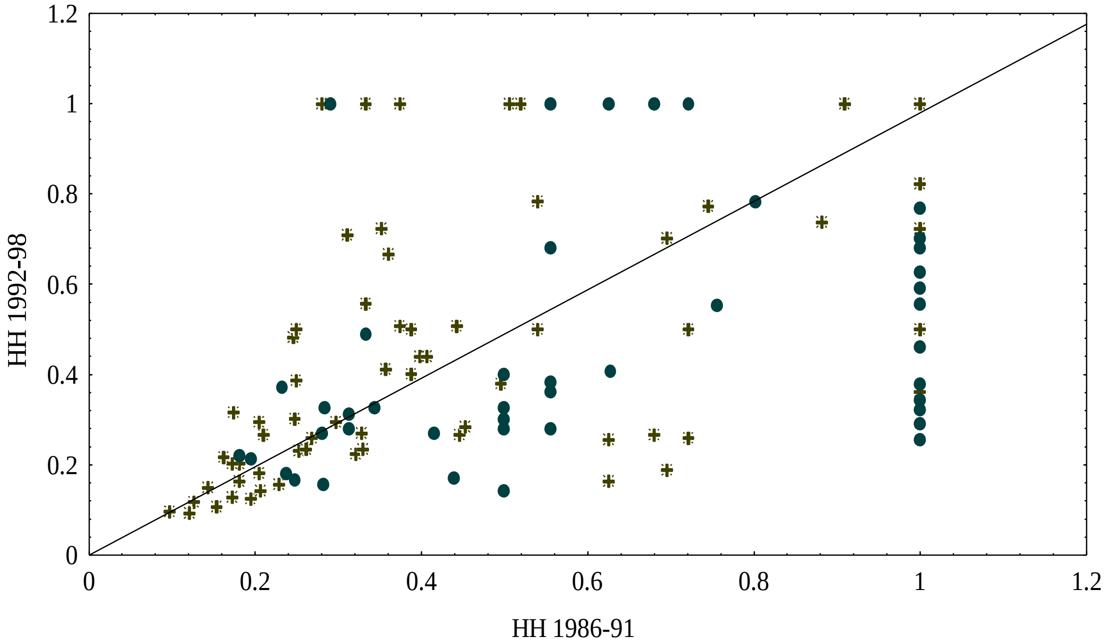


Finally, Chart 4 shows that firms starting to patent in the '90s (THIRDIN) are highly specialised. Almost 80% of all new entrants in the subperiod 1992-98 are highly specialised (i.e. have a Herfindahl index above 0.808).

Quite interesting results emerge also when combining information on size with the extent of technological diversification. Large (> 500 employees) persistent innovators present increasing degrees of technological diversification between the period 1978-85 and the period 1986-91. This trend, however, stops in the following subperiod. A similar trend towards greater levels of technological diversification seems to characterise also the group of small (<100 employees) persistent innovators, while the group of medium size persistent innovators shows high and increasing degrees of technological specialisation. Regarding the second cohoort of entrants (SECOIN), the data indicate univocally for all size categories an increase of technological

Figure 1

Herfindahl Index 1986-91 vs. 1992-98, PERSIST and SECOIN



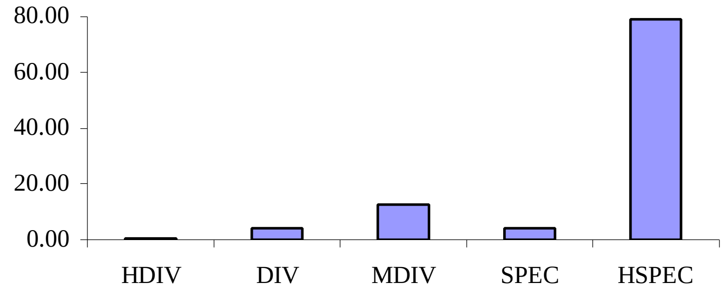
Note: * SECOIN ; • PERSIST.

diversification, while the third cohoort of entrants is characterised by high levels of technological specialisation for all size classes.

Chart 4

Distribution of third cohoort patenting firms (THIRDIN) by degree of technological diversification (Herfindahl index , n=300, %)

1992-98



The analysis conducted so far illustrates the changes in the overall degree of technological specialisation/diversification of electronic firms, but it does not tell us anything about the fields where they are specialised and where they are expanding (or contracting) their activities. To this purpose, we have first calculated, for each country represented in our sample, the distribution of firms patenting in the period 1992-98 by type of technological specialisation/diversification. In particular, we have distinguished 6 subsets of firms: those firms that are active in all three major technological fields of Audiovisual, IT and Telecommunications (DALL); firms that are active both in Audiovisual and IT (AV-IT); firms that are active both in Audiovisual and Telecommunications (AV-TE); firms that are active both in IT and Telecommunications (AV-IT); finally, firms that are active only in one of the three technological fields (AV, IT, TE).

Results reported in Table 5 shows that European countries (with the exception of France) are characterised by a lower share of firms widely diversified in all technological fields compared with Japan and US. On the other hand, firms specialised in Telecommunications represent a much higher share of all patenting firms in Europe than in Japan and US. Like in Japan, firms specialised in Audiovisual technology account for more than one third of all European patenting firms. Conversely, the US present a relatively higher share of firms specialised in Information Technology and diversified in the pair IT-Telecommunications compared to Japan and Europe. These differences in firms' patterns of diversification across countries are confirmed by the calculation of the revealed technological advantage index in the three technological areas (Table 6). This latter has been calculated both with reference to the sample of selected firms and to the whole population of world firms patenting in the three technological fields. Results are quite consistent and show that the major European countries are relatively specialised in the field of Telecommunications, with the exception of Italy, which is relatively specialised in IT. Japan presents instead a strong specialisation in Audiovisual technology, while the US are relatively specialised in Information technology.

From a more dynamic perspective, it is interesting to examine what are the fields where firms are widening their technological activities conditional on their past fields of specialisation. To this end, we have calculated for Europe, Japan and the US, the distribution of firms patenting in the period 1978-98 by type of specialisation in the period 1992-98 (destination class) and type of specialisation in the period 1978-91 (origin class). To define types of specialisation we have used the 6 categories described above. Results are reported in Table 7. Reinforcing our previous findings, in Europe widely diversified firms that continue to be widely diversified account for a much lower share of all patenting firms compared to the US and especially Japan. At the same time, Europe is also characterised by a much higher share of all patenting firms accounted for by firms that were specialised in a single technology and that stop patenting. The overall rate of technological mortality in Europe is thus higher than in Japan and the US, particularly among technologically specialised companies.

Quite surprisingly, the share of new innovative companies that start specialised in one field is similar between Italy and Japan, and is higher than in the US, particularly in Audiovisual technologies. On the other hand, in US and Japan firms that are new innovators, start specialised or are moderately diversified and widen their innovative activities to other fields account for a considerably higher share of all patenting companies.

In brief, Europe seems to be characterised by 'too high' degrees of turbulence compared with Japan and US. Conversely, 'too few' firms persist in innovative activities and widen their technological competencies to other fields.

Table 5

Diversified and specialised firms in Audiovisual, IT and Telecommunications technology
% share of firms by country - (1992-98)

Country	**DALL**	**AV-IT**	**AV-TE**	**IT-TE**	**AV**	**IT**	**TE**	**Total**
Germany	10.34		9.20	8.05	26.44	25.29	20.69	100
France	23.08	7.69	3.85	1.92	30.77	15.38	17.31	100
UK	4.88	2.44	2.44		31.71	34.15	24.39	100
Italy	12.00	8.00	4.00		56.00	8.00	12.00	100
Europe	12.68	7.32	1.95	3.90	32.20	22.44	19.51	100
Japan	17.95	5.98	6.84	4.27	33.33	22.22	9.40	100
US	18.59	8.33	5.13	7.05	18.59	29.49	12.82	100
All countries	15.90	5.65	5.86	5.02	28.03	24.69	14.85	100

DALL=firms active in all 3 fields; AV-IT=firms active in Audiovisual and IT; AV-TE = firms active in Audiovisual and Telecommunications; IT-TE = firms active in IT and Telecommunications; AV=firms active only in Audiovisual; IT=firms active only in IT; TE= firms active only in Telecommunications. 205 firms for Europe, 117 for Japan, 156 for the US.

Table 6

Revealed Technological Advantage (1978-98)

	Sample firms			*All firms*		
	Audiovisual	**IT**	**Telecom**	**Audiovisual**	**IT**	**Telecom**
Germany	0.610	0.915	1.737	1.056	0.688	1.421
France	1.070	0.840	1.129	1.029	0.825	1.239
UK	0.583	1.301	1.204	1.044	0.773	1.301
Italy	0.716	1.728	0.359	0.914	1.114	0.951
Japan	1.205	0.863	0.883	1.278	0.839	0.818
US	0.801	1.404	0.709	0.730	1.303	0.937

'Selected sample' includes only the 621 electronic firms. 'All firms' include all world firms that have patented in the 3 technological fields.

Table 7 – *Distribution of firms patenting in the period 1978-98 by category of origin and destination (percentage values)*

Period 1992-98 / Period 1978-91	DALL	AV-IT	AV-TE	IT-TE	AV
				Europe =100	
DALL	5.99		0.35	1.06	
AV-IT	0.35	0.35			
AV-TE	1.41		1.06		0.35
IT-TE					
AV					2.11
IT		0.70		0.35	
TE			0.35		0.70
NP	1.41	1.41	2.46	1.41	20.07
				Japan=100	
DALL	10.29	0.74	1.47		
AV-IT	1.47			0.74	1.47
AV-TE	0.74				
IT-TE	0.74		0.74	0.74	
AV	0.74	1.47	2.94		6.62
IT		0.74			
TE	0.74		0.74	2.21	
NP	0.74	2.21		2.21	19.85
				United States=100	
DALL	7.35				
AV-IT	1.96	0.98			0.49
AV-TE	0.98		0.49		
IT-TE	0.49			0.49	
AV	0.49	0.98	0.49		3.43
IT	1.47	1.47		0.98	
TE	0.49	0.49	0.49	0.49	
NP	0.98	2.45	2.45	3.43	10.29

DALL=firms active in all 3 fields; AV-IT=firms active in Audiovisual and IT; AV-TE = firms active in Audiovisual and Tel
Telecommunications; AV=firms active only in Audiovisual; IT=firms active only in IT; TE= firms active only in Telecommunicati
136 for Japan, 204 for the US.

6. Relatedness in technological diversification

This section examines whether firms from different countries and firms of certain types (small vs. large, old vs. young, persistent vs. non-persistent innovators) diversify in different ways. To this purpose, we draw on the methodology of Teece et al. (1984) to build a measure of technological "relatedness" between pairs of technologies observed in individual firms. Hence, the frequency of co-occurences between two technological fields within the same firm can be interpreted to imply that the two fields in question are highly related, and viceversa.

Let K be the number of firms active in more than one technology (i.e. diversified) over the period 1978-98. Let G_{it}=1 if firm t patented in technological field i and G_{it}=0 otherwise. The total number of firms having patented in technological field i in the period 1978-98 is therefore given by: $n_i=\sum_t G_{it}$. Using this notation, we can also indicate the number of firms that have patented, i.e. are active, in both technological fields i and j as follows: $J_{ij}=\sum_t G_{it}G_{jt}$. By applying the latter to all possible pairs of technological fields we obtain a square (25x25) symmetrical matrix **J**, whose generic cell J_{ij} reports the number of firms that in the period 1978-98 were active in both technological fields i and j.

A measure of relatedness between any two technological fields i and j can thus be created by comparing the observed number of linkages J_{ij} with the number that would be expected under the hypothesis that technological diversification is random (no relatedness between i and j), given n_i, n_j and K. More particularly, let us assume that in a population of K innovative firms, a number n_i of firms possess the characteristic of being active in technological field i. This implies, of course, that (K - n_i) firms do not possess such characteristic. Now, an independent sample (without replacement) of size n_j of firms is drawn from the population of K innovative firms and these firms are assigned activities in technological field j. Given this experiment, the probability of obtaining exactly x firms that are active in both technological fields i and j is distributed according to a hypergeometric random variable, with population K, special members n_i, and sample size n_j:

$$P[X_{ij} = x] = \binom{n_i}{x}\binom{K-n_i}{n_j - x}\Big/\binom{K}{n_j} \qquad (1)$$

The mean and the variance of X_{ij} are respectively:

$$\mu_{ij} = E(X_{ij}) = n_i n_j / K \qquad (2)$$

$$s_{ij}^{2} = m_{ij}\left(1-\frac{n_i}{K}\right)\left(\frac{K}{K-1}\right) \qquad (3)$$

The measure of technological relatedness is then defined as:

$$t_{ij} = \frac{J_{ij} - m_{ij}}{s_{ij}}, \qquad (4)$$

where J_{ij} is the value of the generic cell of matrix **J** ; m_{ij} and s_{ij} are respectively the mean and variance of the hypergeometric distribution we would expect to obtain under the random hypothesis. This statistic measures therefore the extent to which the observed association between two technological fields exceeds that which would be expected if firms were assigned to technological fields randomly. If the actual number of firms diversified in technological fields *i* and *j* (i.e. J_{ij}) greatly exceeds the expected number m_{ij}, then there must be a strong (non random) relationship between the two technological fields. If, on the contrary, r_{ij} takes a negative value, this means that O_{ij} is even lower than the number we would observe if firms were to choose their technological fields randomly.

We calculated relatedness indexes for all diversified firms in our sample (ALL) and for various subsets of them. Populations EU, US and JP refer to firms from Europe, Japan and the United States. Populations P and NP refer, respectively, to persistent innovators and non persistent innovators (see above). Populations O and Y refer, respectively to old firms (born before 1973) and new firms. Finally, populations L and S refer, respectively to large firms (with more than 500 employees) and small and medium size firms.

Table 8 reports the basic results for the various populations of firms, while Table 9 shows the correlation coefficients for the relatedness index between populations. Although the t_{ij} statistic is not strictly comparable across populations, being sensitive to the values of K n_i and $n_,$, some interesting observations can nonetheless be made:

(i) The average t is in all cases significantly different from zero, thus supporting the conclusion that electronic firms diversify nonrandomly, irrespective of population.

(ii) Japanese firms seem to be more purposively diversified than European and US firms, as indicated by the higher proportion of pairs of technologies with a t>2, and by the higher average t. In turn, European firms appear to be more purposively diversified than US firms.

(iii) Persistent innovators are, on average, more purposively diversified than non-persistent innovators, and the same can be said of the comparison between old vs. new firms, and large vs. small firms.

(iv) The low correlation coefficients indicate that Europe, Japan and the US are characterised by quite different patterns of technological diversification in electronics. In other terms, the combination of technologies within firms is rather different between the three groups of countries.
(v) The result above is reinforced by the information provided in Table B1-Appendix that lists for each population of firms the 15 most related technological fields. European and Japanese firms share only one pair of technologies, while European and US firms share only two of the 15 most related fields.
(vi) Large and small firms present quite different patterns of diversification (low correlation of t), and the same is true for old vs. new firms. Moreover, persistent innovators have quite similar patterns of diversification to the large and old firms.

These results suggest that the average diversification pattern of European firms differs quite significantly from that of Japanese and US firms. At the same time, SMEs and relatively young firms present average patterns of diversification that differ rather considerably from that of large and old firms.

Table 8 - *Measure of technological relatedness*

	ALL	**EU**	**US**	**JP**	**P**	**NP**	**O**	**Y**
K	234	76	95	63	75	159	152	82
I	25	25	25	24	25	25	25	25
J_{ij}*	300	300	300	276	300	300	300	300
J_{ij}	299	299	292	275	299	237	294	289
% of J_{ij} with t>2	78.595	47.157	38.869	66.545	41.304	23.206	71.938	39.100
Sum t_{ij}	1981.702	1150.567	1012.826	1336.833	1086.119	361.8534	1685.035	960.2154
Max t_{ij}	8.723	5.588	5.624	5.249	4.517	5.976	7.648	8.945
Min t_{ij}	-0.721	-1.531	-1.008	-0.607	-0.967	-2.028	-1.032	-1.573
Mean t_{ij}	3.303	1.918	1.688	2.422	1.810	0.603	2.808	1.600
Std. Dev. t_{ij}	1.571	1.195	1.266	0.997	0.964	1.347	1.482	1.278
Var t_{ij}	2.468	1.429	1.603	0.994	0.929	1.815	2.196	1.632
Normality test for t	114.414	66.428	58.476	80.468	62.707	20.892	97.286	55.438

ALL: all firms in the sample
EU: European firms
US: US firms
JP: Japanese firms
P: Persistent innovators
NP: Non persistent innovators
O: firms founded before 1973
Y: firms founded after 1973
L: large firms with more than 500 employees
S: small firms with less than 500 employees
K: firms active in more than one technology
I: technologies where firms are active
J_{ij}*: all possible pairs of technological activities
J_{ij}: observed pairs of technological activities
Normality test for t is defined as: $T = \sum t_{ij} / \sqrt{I(I-1)/2}$, which under the assumption of independently distributed t_{ij}

Table 9

Correlation coefficient for t_{ij}

	ALL	EU	US	JP	P	NP	O	Y	L
ALL									
EU	0.774								
US	0.736	0.356							
JP	0.619	0.280	0.217						
P	0.874	0.675	0.646	0.528					
NP	0.704	0.557	0.563	0.388	0.441				
O	0.936	0.654	0.695	0.699	0.808	0.613			
Y	0.569	0.627	0.401	0.216	0.514	0.532	0.264		
L	0.937	0.655	0.702	0.655	0.843	0.667	0.909	0.471	
S	0.587	0.620	0.390	0.189	0.504	0.470	0.458	0.584	0.267

ALL: all firms in the sample
EU: European firms
US: US firms
JP: Japanese firms
P: persistent innovators
NP: non-persistent innovators
O: firms founded before 1973
Y: firms founded after 1973
L: large firms with more than 500 employees
S: small firms with less than 500 employees
All correlations statistically significant.

7. Age of technologies and technological diversification

The age of technologies is a key factor to understand the role played by new firms in the innovation process and to assess firms' patterns of technological diversification. Recent works (Utterback, 1994; Klepper 1996) have clearly shown that during the evolution of industries changes may occur in the patterns of innovation. According to an industry life cycle view, at the beginning of an industry, when technology is new and is changing very rapidly, uncertainty is very high and barriers to entry are low, new firms play a major role as innovators and are key elements in industrial dynamics. When the industry develops and eventually becomes mature, and technological change follows well-defined trajectories, economies of scale, learning curve, barriers to entry and financial resources become important in the competitive process. Thus, large firms with market power come to forefront of the innovation process.

To ascertain the age of different technologies is not a simple task, however. In this paper, we used the following methodology to distinguish between 'mature' and 'new' electronic technologies. In the first place, the 25 technological microclasses used in the previous analysis have been disaggregated into 57 subfields. The main reason for doing so is that within each of the 25 technological microclasses one can find technologies at very different stages of their life cycle. For each of the 57 subfields, we then used a combination of three criteria to define what are the 'mature' and what are the 'new' electronic technologies:

i) First, we used information on the additions and changes over time to the International Patent Classification (IPC). The IPC includes indication of the edition where a given IPC entry has first appeared or has been substantially changed. The IPC is revised every five years. The current edition (6^{th}) was introduced in 1995. As each IPC entry relates to a certain technology, entry changes or additions reflect (with some delay) *changes in technology* or *the emergence of new technologies*. As a first step, we have then defined 'mature' those technologies that have not been undergoing any change or addition since the third edition (1980-84), and 'new' technologies all the others. [2]

ii) This preliminary aggregation has been tested through the analysis of the world growth rates of patents for each of the 57 technical subfields. To this purpose, we used two sources of data: EPO (European Patent Office- from 1978 to 1998) and USPO (United States Patent Office – from 1976-1998).

iii) Thirdly, the results from the two previous steps have been checked through personal interviews to experts and scientists in the field. Questions were directed to establish

[2] We wish to thank Keith Pavitt for suggesting us this approach to measuring the age of technologies.

whether the technology was developed before or after the 80's, and to what extent it was characterised by high or low dynamism.

The classification of 'mature' and 'new' electronic technologies is reported in the Appendix (Table A2). Within 'new' technological fields, audiovisual technologies weights for more than 47% of all patents, whereas the share of IT and Telecommunications is respectively 17.5% and 31.5%. Within 'mature' technologies, the share of patents within IT rises to 50.8%, while the share of Audiovisual and Telecommunications is respectively 30.0% and 23.2%.

If we compare the distribution of patents between 'mature' and 'new' technologies among countries, we observe that in general Europe is characterised by a remarkable specialisation into 'mature' technological fields (see Tables 10 and 11). This is particularly so for Germany and the UK. At the same time, it is quite surprising to note that also the United States seem to be relatively specialised into mature technologies. On the other hand, Japan shows a clear pattern of specialisation in new technological fields.

Table 10

Distribution of patents according to the age of technologies: by country (1992-98)

Country	**% Mature**	**% New**	**Total**
Germany	76.39	23.61	100
France	65.71	34.29	100
UK	81.82	18.18	100
Italy	61.64	38.36	100
Europe	73.6	26.4	100
Japan	50.55	49.45	100
US	71.64	28.36	100

Table 11

Revealed technological advantages (1992-98)

Country	Mature technologies	New technologies
Germany	1.22	0.63
France	1.06	0.89
UK	1.28	0.53
Italy	0.90	1.16
Japan	0.81	1.33
US	1.13	0.79

Table 12

Distribution of firms and patents across countries by new and mature technologies (1992-98)

Country	**Firms**		**Patents**	
	% Mature	% New	% Mature	% New
Germany	20.42	18.06	18.89	9.42
France	10.88	9.68	7.47	6.29
UK	9.73	4.52	0.89	0.32
Italy	4.96	5.16	1.85	1.86
Europe	45.99	37.42	29.11	17.89
Japan	21.18	26.77	39.22	61.89
US	32.82	35.81	31.67	20.22
Total	*100*	*100*	*100*	*100*

Table 13

Distribution of patents across countries by firm size, New and mature technologies (1992-98)

Country	Large firms		SMEs	
	% Mature	% New	% Mature	% New
Germany	13.23	5.37	19.31	11.70
France	7.54	5.47	4.01	5.95
UK	0.67	0.35	5.65	2.46
Italy	0.01	0.02	22.59	38.60
Europe	21.45	11.21	51.56	58.71
Japan	42.33	63.78	5.56	9.03
US	36.23	25.01	42.90	32.24
Total	*100*	*100*	*100*	*100*

Large firms = more than 500 employees
SMEs = less than 500 employees

Similar results are obtained by comparing the distribution across countries of patents in new and mature technologies (Table 12). Europe's share of patents in mature fields (29.11%) is consistently higher than its share of patents in new technologies (17.89%). The opposite holds for Japan (39.22% and 69.81%), while the US weights more in new than in mature technologies in terms of firms, but not in terms of patents. Moreover, it is also quite interesting to note that the share of Europe is remarkably higher in terms of firms than patents, both for mature and new fields, thus indicating a lower average number of patents per firm.

Table 13 shows the contribution of large and SMEs to the production of patented inventions in mature and new fields. The share of large European firms is remarkably lower than the share of European SMEs, both in mature and new technologies. Large European firms account only for 11.21% of all patents produced by large electronic firms, while the share rises to 58.71% if one considers small and medium-size enterprises. Moreover, it seems also important to note that the share of European SMEs in new technologies is higher than the corresponding share in mature fields, while the opposite holds for large European companies. These results together seem to suggest that in Europe SMEs and young firms represent the main engines of innovation and competence accumulation in electronic technologies, particularly compared to Japan (see also Table 14).

This conclusion is further corroborated by the evidence on the distribution of firms by type of technological specialisation (Table 15). Firms specialised in mature technologies weight disproportionately more in Europe (56.37%) than in Japan (41.02%) and United States (42.94%), whereas the opposite occurs regarding the role of diversified firms.

From a more dynamic perspective, Table 16 reports the distribution of firms patenting in the period 1992-98 by type of current specialisation and type of specialisation in the previous period of time 1978-91. A first result to point out is that in Europe, compared with Japan and the US, a remarkably higher share of all patenting firms is represented by net entrants (not patenting before 1992) that start specialised in mature technological fields. At the same time, one can also note that diversified firms that continue to be diversified account for a much lower share of all patenting firms in Europe, compared to Japan and United States. On the other hand, the situation for Europe compares more favourably if one looks at the share of net entrants that start either diversified or specialised in new technological fields.

Table 14

Distribution of patents across countries by firm age, New and mature technologies (1992-98)

Country	New firms		Old firms	
	% Mature	% New	% Mature	% New
Germany	5.29	7.33	17.78	6.64
France	24.30	27.50	2.02	0.83
UK	2.33	1.37	0.95	0.37
Italy	0.59	1.28	0.11	0.02
Europe	32.51	37.48	20.86	7.86
Japan	2.52	2.11	51.36	74.26
US	64.97	60.40	27.78	17.88
Total	*100*	*100*	*100*	*100*

Old firms = founded before 1973
New firms = founded after 1973

Table 15

Diversified and specialised firms (1992-98) – percentage and absolute values

Country	Diversified	Specialised		Total
		Mature	New	
Germany	34.09 (30)	51.13 (45)	14.77 (13)	100
France	42.00 (21)	50.00 (25)	8.00 (4)	100
UK	9.75 (4)	80.50 (33)	9.75 (4)	100
Italy	28.00 (7)	48.00 (12)	24.00 (6)	100
Europe	30.39 (62)	56.37 (115)	13.23 (27)	100
Japan	37.60 (44)	41.02 (48)	21.36 (25)	100
US	41.02 (64)	42.94 (67)	16.02 (25)	100
All countries	35.6 (170)	48.21 (230)	16.14 (77)	100

'Diversified firms' patent both in mature and new technologies. 'Specialised firms' patent only in new or mature technologies.

All in all, these results seem to suggest a twofold explanation for the European weakness in new or emerging electronic technologies. On the one hand, the lack of a stable core of large firms with diversified competencies in mature and new technologies, and on the other hand a 'too high' entry of small firms specialised in mature technologies and unable to widen their specialisation from mature to emerging fields.

Table 16 – *Distribution of firms patenting in the period 1992-98 by category of origin and destination (percentage and al*

Period 1992-98	Diversified in mature and new	Specialised in mature	Specialised in new	Diversified in mature and
Period 1978-91				
		Germany		
Diversified in mature and new	13.64 (12)	2.27 (2)		22.00 (11)
Specialised in mature	7.95 (7)	9.09 (8)		4.00 (2)
Specialised in new	1.14 (1)			2.00 (1)
Not patenting	11.36 (10)	39.77 (35)	14.77 (13)	14.00 (7)
		UK		
Diversified in old and new	2.44 (1)	4.88 (2)		8.00 (2)
Specialised in mature		4.88 (2)	2.44 (1)	4.00 (1)
Specialised in new			4.88 (2)	8.00 (2)
Not patenting	7.32 (3)	70.73 (29)	2.44 (1)	8.00 (2)
		Europe		
Diversified in mature and new	12.74 (26)	1.96 (4)		22.22 (26)
Specialised in mature	4.90 (10)	6.86 (14)	0.49 (1)	2.56 (3)
Specialised in new	1.96 (4)	0.49 (1)	1.47 (3)	4.27 (5)
Not patenting	10.78 (22)	47.05 (96)	11.27 (23)	8.55 (10)
		US		
Diversified in mature and new	24.36 (38)	3.85 (6)	0.64 (1)	18.86 (90)
Specialised in mature	3.85 (6)	8.97 (14)	0.64 (1)	3.98 (19)
Specialised in new	3.21 (5)		3.85 (6)	2.93 (14)
Not patenting	9.62 (15)	30.13 (47)	10.90 (17)	9.85 (47)

'Diversified firms' patent both in mature and new technologies. 'Specialised firms' patent only in new or mature techno
patent before 1992.

Table 17 – *Determinants of patenting in new technologies, 1992-98*

Dependent variable	**Patent/Not patent**		**Count of patents**	
	Logit		Poisson	
Intercept	-1.26	***	-0.2201	
	(0.5144)		(0.2599	
StockMature	0.4328	**	-0.034	
	(0.1729)		(0.041)	
StockNew	1.6554	***	0.8849	***
	(0.2325)		(0.044)	
PatOld	-0.6256	***	0.6173	***
	(0.246)		(0.1888)	
Age	-0.3602	***	-0.3016	***
	(0.1446)		(0.0607)	
NetEntry	1.7058	***	-0.3151	
	(0.3495)		(0.2019)	
Dummy Large	1.1338	***	0.8391	***
	(0.2281)		(0.1717)	
Dummy US	0.000814		0.7747	***
	(0.2517)		(0.1194)	
Dummy Japan	0.2983		0.8454	***
	(0.2818)		(0.1237)	
Scale			2.6416	
Observations	561		561	
			Scaled Pearson Chisq 1.852	
			Log-Likelihood 3354.54	

Standard errors in parentheses.
a) RTA standardised to range between (-1,+1).
** significant at the 95% level; *** significant at the 99% level.

8. A regression analysis of patenty in new electronics technologies

In order to gain a better understanding of the factors affecting the patenting behaviour in new or emerging electronic technologies, we have performed regression analysis on three dependent variables: a) a binary variable, taking value 1 if firm i was patenting in new technological fields in the period 1992-98; 0 otherwise; b) a count variable defined as the total number of patents firm i has taken in new technologies over the period 1992-98; c) a specialisation index in new technologies given by the revealed technological advantage over the period 1992-98.

The model estimated has the following form:

$$Y = a + b_0 StockMature + b_1 StockNew + b_2 PatOld + b_3 Age + b_4 NetEntry + b_5 DL\arg e + b_6 DUS + b_7 DJP + (e) \quad (5)$$

where:

- *StockMature* is the (log of) total number of patents of firm i in 'mature' technologies over the period 1978-91
- *StockNew* is the (log of) total number of patents of firm i in 'new' technologies over the period 1978-91
- *PatOld* is a dummy variable taking value 1 if firm i is active in 'mature' technologies in the period 1992-98; 0 else
- *Age* is the age of firm i in 1998
- *NetEntry*: is a dummy variable taking value 1 if firm i was not patenting in any field in the period 1978-91; 0 else
- *Dlarge*: is a dummy variable taking value 1 if firm i is a large firm (> 500 employees); 0 else
- *DUS*: is a dummy variable for US firms
- *DJP*: is a dummy variable for Japanese firms

The estimation results are presented in Table 13. The coefficient of *StockNew* is positive and statistically significant in all cases, thus indicating that a higher accumulated stock of patents in new technologies determines a higher probability of being active in new technologies, a higher expected number of patents produced in new fields, and a relatively higher degree of specialisation in the same fields. On the other hand, the accumulated stock of patents in mature technologies (*StockMature*) positively affect the likelihood of being active in new fields, but it has a negative impact on the specialisation in new technological areas. Firms with large accumulated competencies in mature fields thus open up windows on new technologies, without however switching their specialisation. The negative coefficient on the variable *Age* indicates that *ceteris paribus* younger firms tend to enter new technological fields and produce a larger number of innovations in those fields. However, the age of firms does not seem to have any effect on the degree of specialisation in new technologies. New patenting firms (*Net Entry*) have a greater likelihood of being active in new fields, but they are also relatively despecialised in those fields. The size of firms (*DLarge*) seems to affect the probability of patenting in new technologies and is associated to a greater expected number of patents, but it does not have any significant effect upon specialisation in new technologies. Finally, US and Japanese firms produce a larger number of patents in new technologies compared to European firms. However, Japanese firms appear to be significantly more specialised in new technological fields compared with European and US firms.

9. Conclusions

This paper has shed light on the processes of *technological diversification and specialization* by firms. It starts from the recognition that technological diversification is a widespread phenomenon in Europe, the United States and Japan. Generally speaking, only occasional innovators are not technologically diversified. On the contrary, most persistent innovators are diversified in at least two technologies. This implies that most firms have to master and integrate different technologies in their products and processes in order to survive as innovators (and possibly also as manufacturers). Previously, we found that firms diversify along certain directions which reflects the working of local search, spillover, complementarities and proximity mechanisms. Looking ta the whole spectrum of technologies, four major clusters of technologies in which firms are diversified emerge: chemicals and bio-pharmaceuticals, materials, mechanical and process technologies, and electrical and electronic technologies.

In this paper, the processes of technological diversification and specialization by European, American and Japanese firms have been examined in 25 technological fields within telecommunications, information and audiovisual technologies for the period 1978-1998.

What conclusions can be advanced from our analysis?

a. First, in electronics technologies incumbent firms are engaged in continuous processes of technological diversfication, opening up windows on new technologies. On the contrary new innovators tend to start highly specialized and most of them remain so.

b. The balance between technologically diversfied firms and new entrants *is quite different across technologies*, reflecting the working of different technological and learning regimes even within families of technologies such as telecommunications, audiovisual, and information technologies. New technological entrants are relatively more important in the following microclasses: coding and decoding, data recognition and presentation, broadcast systems, microphones, pulse techniques, secret communication, transmission of measured values, aerials. Technological diversifying companies have a relatively high share of patents in the following microclasses: speech analysis, optical computing, telephones, broadcast systems, microphones, secret communication, aerials and error detection.

c. The great majority of firms in only one of the 25 microclasses.

d. The most diversified firms are also the largest innovators. During the 1980s, the role of diversified corporations increased: several incumbent innovators have started their innovative activities as specialized and then have diversifed their activities into new technologies. However this process of increasing technological diversfication seems to fade during the 1990s.

e. As far as the features of technological diversification are concerned, persistent innovators are, on average, more purposively diversified than non-persistent innovators.

f. Differences in the patterns of diversification and specialization emerge between the old and the new firms, and between the large and the small firms. In general *small and relatively young firms* present patterns of diversification that are similar amongst them, and that differ rather considerably from that of the large and old firms. Moreover persistent innovators have quite similar patterns of diversification to the large and old firms.

g. These outcomes are summarized by regression results about *patenting in new technologies*. Firms with large accumulated competencies in mature fields thus open up windows on new technologies, without however switching their specialisation. Ceteris paribus younger firms tend to enter new technological fields and produce a larger number of innovations in those fields. However, the age of firms does not seem to have any effect on the degree of specialisation in new technologies: new patenting firms have a greater likelihood of being active in new fields, but they are also relatively despecialised in those fields. National systems of innovation effects seem to play a major role: US and Japanese firms produce a larger number of patents in new technologies compared to European firms. However, Japanese firms appear to be significantly more specialised in new technological fields compared with European and US firms.

h. A closer examination of the role of *national systems of innovation* shows the following results. As far as persistent innovators are concerned, in Germany, US and Japan persistent innovators account for a larger share of all patenting firms and patents compared to the other European countries. Among the European countries, only Germany presents a comparable share of patents held by this category of firms.

l. If we look at all the technologies, European countries (with the exception of the UK) present a considerable degree of dynamism in terms of technological entry of new patenting firms. However, such firms are more likely to enter with a relatively low number of patents and in a less persistent fashion, particularly compared to the US. In fact, the overall rate of technological mortality in Europe is higher than in Japan and the US, particularly among technologically specialised companies.

m. On the contrary, in the United States and Japan firms that are new innovators start specialised or are moderately diversified, and with time they widen their innovative activities to other fields account for a considerably higher share of all patenting companies.

n. European countries (with the exception of France) are characterized by a lower share of firms widely diversfied in all electronics fields compared to Japan and the US. Firms specialized in telecommunications represent a much higher share of all patenting firms than in the US and Japan (while the US present a relatively higher share of firms specialized in information technologies). Japanese firms seem to be more purposively diversified than European and US firms. Moreover Europe, Japan and the US are characterised by quite different patterns of technological diversification in electronics, as indicated by the combination of technologies within firms is rather different between the three groups of countries.

o. In sum, from the general point of view the United States exibits an high degree of overall dynamism in terms of entry of new and diversified innovators in almost all technological microclasses. On the contrary has a 'too high' degrees of turbulence compared with Japan and US: 'too few' firms persist in innovative activities and widen their technological competencies to other fields.

p. If we break our technological classes into new and mature, Europe is characterised by a remarkable specialisation into '*mature*' technological fields. This is particularly so for Germany and the UK. At the same time, it is quite surprising to note that also the United States seem to be relatively specialised into mature technologies, but only in terms of patents (and not of firms). On the other hand, Japan shows a clear pattern of specialisation in new technological fields.

q. As a consequence of the previous points, in Europe, compared with Japan and the US, a remarkably higher share of all patenting firms is represented by net entrants (not patenting before 1992) *that start specialised in mature technological fields*. At the same time, those diversified firms that continue to be diversified account for a much lower share of all patenting firms in Europe, compared to Japan and United States.

r. Relatedly, the share of large European firms is remarkably lower than the share of small European firms, both in mature and new technologies. Moreover, the share of small European firms in new technologies is higher than the corresponding share in mature fields (while the opposite holds for large European companies). Thus small and young European firms are the main engines of innovation and competence accumulation in electronic technologies, particularly compared to Japan .

s. From this analysis an explanation of the European weaknesses in electronics technologies based on the weaknesses of both the core and the fringe of European innovators emerges. As far as the core is concerned, in electronics Europe does not have a big core of numerous large competent companies that span over mature as well as new technologies. In this way, big projects on broad technologies, the continuous opening of windows on new technologies and the pursue of multitechnology initiatives that requite the integration of different complementary technologies may be unpaired. As far as the fringe of innovators is concerned, Europe is characterized by a too high entry of small firms specialised in mature technologies. The problem here is not entry but survival. Most of the new innovators are not able to become continuous innovators and do not survive as innovators for long. Even those that survive are unable to widen their specialisation, and move from mature to emerging technological fields.

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Appendix A

Table A1 - The 25 technological microclasses from Audiovisual Technology (AV), Telecommunications (TC) and Information Technology (IT)

1 Coding decoding (AV, IT, TC)	13 Optical transmission (TC)
2 Displays (AV)	14 Telephones (TC)
3 Stores with relative movement (AV, IT)	15 Fax terminals TC)
4 Solid body stores (AV, IT)	16 TV systems (AV, TC)
5 Speech analysis or sinthesys ((IT)	17 Broadcast systems (AV, TC)
6 Data recognition and presentation (IT)	18 TV sets and cameras (AV)
7 Data input and output (IT)	19 Microphones. loud-speakers. stereo systems (AV)
8 Electrical data processing (IT)	20 Amplifiers. tuners. oscillators (AV, TC)
9 Optical computing (IT)	21 Pulse technique (IT, TC)
10 Switching (TC)	22 Secret communication (TC)
11 Electrical transmission (TC)	23 Transmission of measured values (TC)
12 Radio transmission (TC)	24 Aerials (AV, TC)
	25 Error detection and transmission control (IT, TC)

Table A2 - Microclasses and IPC classes: new and mature technologies

Microclass	Field	IPC Class	Stage of LC
1	1	H03M	Mature
2	2	G09F	Mature
	3	G09G	Mature
3	4	G11B	New
4	5	G11C	New
5	6	G10L	New
6	7	G06K	Mature
7	8	G06F3	Mature
8	9	G06F1	Mature
	10	G06G	Mature
9	11	G06E	New
10	12	H04L11	New
	13	H04M15	Mature
	14	H04M19	Mature
	15	H04M3	Mature
	16	H04Q	Mature
11	17	H04B1	New
	18	H04B3	Mature
	19	H04J	New
	20	H04L13	Mature
	21	H04L25	Mature
	22	H04L27	Mature
	23	H04L5	New
	24	H04L7	Mature
12	25	H04B7	Mature
	26	H04Q7	Mature
13	27	H04B10	New
	28	H04B9	Mature
	29	H04J14	New
14	30	H04M1	Mature
15	31	H04N1	New
16	32	H04N11	Mature
	33	H04N7	Mature
17	34	H04H	New
18	35	H04N13	New
	36	H04N15	New
	37	H04N17	Mature
	38	H04N3	Mature
	39	H04N5	Mature
	40	H04N9	New
19	41	H04R	Mature
	42	H04S	New
20	43	H03B	Mature
	44	H03C	Mature
	45	H03D	Mature
	46	H03F	Mature
	47	H03G	Mature
	48	H03J	Mature
21	49	H03K	Mature
22	50	H04K	New
	51	H04L9	New
23	52	G08C	Mature
	53	H04Q9	Mature
24	54	H01Q1	New
25	55	H03M13	New
	56	H04L1	Mature
	57	H04L29	New

Appendix B

Table B1 – 15 most related technological fields

All firms		**Europe**		**United States**		**Japan**
(1)	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**
Solid body stores	Displays	Displays	Solid body stores	Solid body stores	Displays	Error detection
Error detection	Speech analysis	Fax	Solid body stores	Fax	Speech analysis	TV systems
Fax	Speech analysis	Error detection	Secret commun.	Displays	TV sets	Displays
Speech analysis	Fax	Error detection	Speech analysis	TV systems	TV sets	Speech analysis
Data recogn.	Fax	Ele. data proc.	Fax	Error detection	TV systems	Error detection
Displays	Speech analysis	TV systems	Broadcast	Stores r.m.	Fax	TV systems
TV sets	Displays	Coding	Optical comp.	Displays	Speech analysis	TV systems
Data recogn.	Speech analysis	Speech analysis	Optical comp.	Stores r.m.	Speech analysis	Switching
Switching	Error detection	TV sets	Broadcast	Data recogn.	Fax	Switching
TV systems	Secret commun.	Displays	Stores r.m.	Error detection	Speech analysis	Switching
Pulse techn.	Solid body stores	Stores r.m.	Solid body stores	Pulse techn.	Solid body stores	Error detection
Error detection	TV systems	Data recogn.	Speech analysis	Switching	Error detection	Fax
Speech analysis	Optical comp.	TV sets	Secret commun.	Radio transm.	Speech analysis	Optical transm.
Solid body stores	Speech analysis	Switching	Telephones	Error detection	Switching	Broadcast
Error detection	Secret commun.	Data recogn.	Fax	Error detection	Displays	Solid body stores

Persistent innovators		**Non persistent inn.**		**Old firms**		**New firms**
(1)	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**
Solid body stores	Displays	Solid body stores	Displays	Solid body stores	Displays	Coding
Data recogn.	Speech analysis	Error detection	Speech analysis	Error detection	Speech analysis	Fax
Error detection	Speech analysis	Pulse techn.	Solid body stores	TV systems	Secret commun.	Broadcast
Data recogn.	Data I/O	TV sets	TV systems	Displays	Speech analysis	TV systems
Switching	Telephones	Solid body stores	Pulse techn.	Error detection	TV systems	Data recogn.
Displays	Speech analysis	Radio transm.	Error detection	Solid body stores	Speech analysis	Error detection
Radio transm.	Broadcast	Fax	Speech analysis	Fax	Speech analysis	Solid body stores
Solid body stores	Speech analysis	Amplifiers	Pulse techn.	Switching	Error detection	Switching
Speech analysis	Optical comp.	Error detection	Radio transm.	TV sets	Displays	Data recogn.
Data recogn.	Fax	Radio transm.	Speech analysis	TV sets	Solid body stores	Speech analysis
Broadcast	Microphones	Telephones	Microphones	Error detection	Displays	Aerials
TV sets	Displays	Optical transm.	Optical comp.	TV systems	Speech analysis	Telephones
TV systems	Broadcast	Speech analysis	Radio transm.	Displays	Error detection	Telephones
Broadcast	Radio transm.	Data recogn.	Fax	Switching	Speech analysis	Radio transm.
TV systems	Secret commun.	Switching	Error detection	Error detection	Secret commun.	Radio transm.