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KNOWLEDGE COMPLEXITY AND THE EVOLUTION OF THE AUTOMOTIVE INDUSTRY IN EUROPE

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KNOWLEDGE COMPLEXITY AND THE EVOLUTION OF THE AUTOMOTIVE INDUSTRY IN EUROPE[1].

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ABSTRACT.

Technological complexity measures the extent of the technological diversification in the main fields of the standard scientific classification of the flows and stock of patents, held by each company, that is necessary to generate new technological knowledge. The paper investigates the relations between the technological complexity of the flow of patents delivered to the main European automobile companies and the evolution of their performances in terms of markets share. Technological complexity confirms to be an important characteristic of private knowledge: it exerts strong and positive effects on the competitive advantage of firms. Appropriate measures of technological complexity make it possible to qualify the quantitative measures of the technological competence of firms based upon patents counts.

KEY WORDS: TECHNOLOGICAL COMPLEXITY, COMPETITIVE ADVANTAGE, EUROPEAN AUTOMOBILE INDUSTRY, PATENTS.

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1. INTRODUCTION.

The paper investigates the relations between technological complexity, defined in terms of the extent of the technological diversification across the fields of classification of the flows and stock of patents held by the main European automobile companies, and the evolution of their performances in terms of markets share. Technological complexity is an important qualitative characteristic of private knowledge. Appropriate measures of technological complexity make it possible to qualify the quantitative measures of the technological competence of firms based upon patents counts. Technological complexity can contribute to elaborate a stronger and more reliable measure of the relevance of innovations introduced by firms. As such it is expected to exert strong and positive effects on the competitive advantage of firms. The rest of the paper is structured as follows. Section 2 presents the notion of technological complexity and introduces the main hypothesis of the work, i.e. the relationship between innovation and markets shares in a given product market. Section 3 puts the notion of technological complexity in the context of the search for a proper measure for innovativeness. Section 4 presents the empirical evidence about the evolution of the technological complexity of the main European car makers in the last twenty years of the XX century and the parallel evolution of their market shares. Section 4 also provides an econometric assessment of the relationship between technological complexity and the competitive advantage of firms. The conclusions summarize the main results and put them in perspective.

2. TECHNOLOGICAL COMPLEXITY AND THE COMPETITIVE ADVANTAGE.

Technological complexity of the knowledge base has been recently identified as an important property of the technological competence and innovative capability of firms (Wang and Tunzelmann, 2000).

Much recent progress in the economics of knowledge has made it possible to identify a variety of processes by means of which technological knowledge is generated and a variety of characteristics of technological knowledge. Technological knowledge accumulated and generated within firms is the result of the mix of internal and external knowledge. In turn internal knowledge is generated by means of learning processes and research and development expenditures (Arrow, 1962a). External knowledge is acquired in a variety of ways, including the direct purchase of technological knowledge in the form of patents, services and intermediary research products delivered by third parties. Socialization and receptivity, based upon absorptive capabilities of tacit knowledge also contribute the generation of new knowledge at the firm level. The recipe upon which the generation of new knowledge is implemented at the firm level, varies according to the localized characteristics of the existing knowledge and the structure of the relations in place within industrial and regional systems (Antonelli, 2003).

Technological knowledge is not homogeneous. On the opposite it is articulated in modules that differ with respect to an array of characteristics. Building upon the traditional arrovian categories of appropriability, indivisibility, tradability and expandibility, much progress has been made (Arrow, 1962 and 1969). The modules of technological knowledge are now seen to differ also in terms of cumulability, fungibility and complexity. Technological knowledge exhibits high levels of fungibility when it applies to a wide range of products and processes. The fungibility of technological knowledge applies moreover to the extent to which each unit of knowledge is relevant for the production of other knowledge. Technological cumulability consists in the vertical complementarity between units of knowledge and it is measured by the units of knowledge that precede a new one. Finally, technological complexity is defined by the variety of units of technological knowledge that are necessary and complementary in the production of a new product or process, as well as of a new unit of knowledge.

The assessment of the characteristics of such technological knowledge can contribute substantially the analysis of the relationships between innovation and market performances

The relationship between innovation and market share is one of the cornerstones of economics of innovation and industrial organization at large. Following the basic intuition of Joseph Schumpeter, innovators are expected to take advantage of their technological leadership in terms of profitability and market shares. The introduction of innovations engenders a competitive advantage and hence a transient market power for innovators. In a market characterized by monopolistic competition, innovators can benefit of transient market power because either their products attract new consumers, shifting them away from the demand for the products of rivals or because the reduction in production costs and hence market prices for existing products favours the increase in the quantity chosen by both old and new consumers. The entry of imitators and the adoption of the new products and/or processes by the other incumbents will eventually reduce the market power and hence the market shares of innovators (Stoneman, 1995; Cohen, 1995; Audretsch and Klepper, 2000).

Quite surprisingly the empirical assessment of this typical Schumpeterian relationship, hardly contested at the theoretical level, is scarce. Only Audretsch (1995a) and Brouwer and Kleinknecht (1996) have recently provided some microeconometric evidence testing the effects of innovative conduct on market shares and performances at large.

Much more effort has been dedicated, in the empirical literature to assess the other Schumpeterian hypotheses: which market form is more conducive to foster the rates of introduction of technological innovations and specifically whether market concentration has a positive effect on the rate of introduction of innovations and what is the relationship between innovation efforts and the size of firms. In the former case much empirical evidence has confirmed that oligopolistic markets forms are most appropriate to sustain innovative efforts. In the latter case the empirical analyses have confirmed that large firms fund research and development activities more intensively and systematically than small firms. Small firms however have more chances to introduce radical innovations (Scherer, 1984 and 1999; Audretsch, 1995).

A major shift has occurred in debate on the assessment of the Schumpeterian hypotheses from the original specification of innovation towards more reliable measures of research and development expenditures and eventually patents. The accurate measurement of the actual amount of innovations introduced, rather than the innovative efforts measured by R&D expenditures, or the number of innovation for which intellectual property rights are sought, is central to assessing properly the relationship between innovation and markets share. The empirical assessment of the relationship between innovation, as an independent variable, and market shares, as the dependent variable, requires that a suitable measure for innovation is elaborated and applied (Patel and Pavitt, 1995).

3. TECHNOLOGICAL COMPLEXITY AND THE MEASUREMENT OF INNOVATION.

The measurement of the relevance and the size of innovations is not an easy task. Here different waves of empirical efforts can be traced. Innovation counting is complicated by the complex task of assessing the relevance of innovations. The quantification of a myriad of qualitative issues has always proved a major obstacle to all attempts to measure innovation.

For a long time innovations have been measured by means of the size of the research and development activities carried out by innovating firms. The size of the main input into the production of knowledge, i.e. the amount of expenditures in research and development activities have been considered as a reliable indicator of their output, that is the volume of innovations introduced by means of research activities.

In a third step the variance among firms in both the efficiency of research and development activities and the role of other forms of innovative efforts have been appreciated. Firms differ in terms of the efficiency of their R&D activities: hence the measures of the inputs are no longer regarded as a reliable indicator of the output. Firms in fact differ with respect to the variety of inputs into the innovative activities. Learning especially matters and contributes the amount of innovations a firm is able to introduce. Technological externalities also contribute the innovative process. The proximity of firms and their location play a role in terms of the opportunity to access external knowledge and to make use of it to introduce new technologies. Recently technological outsourcing and Merger&Acquisitions finalized to internalize external knowledge have become more and more common and complicated further the reliability of sheer in house R&D statistics (Pisano, 1990).

In a fourth step the measurement of innovations has been based on patent counting. Patent counting has many benefits in terms of the measurement of the actual relevance of an innovation. On-line access to patent data base has made more and more reliable and widespread the empirical analyses on the stock and the flow of patents delivered to firms as an indicator of the strength and consistency of the technological base of each firm. Patent citations provide reliable information on the relevance of the each patent (Griliches, 1990; Pavitt, 1988).

Also patent counting exhibits its own limitations as an economic indicator. Not all proprietary technological knowledge is patented. The propensity to patent differs widely across industries, countries and even firms within the same country and the same industry. Firms often rely upon secrecy or simply lead-times as an effective mechanism to increase appropriation. The quality of patents, that is their real content in terms of technological novelty, differs widely among technological classes and even within technological classes. Only a fraction of the patents assigned are really used in economic life for uses that are not strategic or little more than attempts to pre-empty the enter of competitors (Griliches, 1990; Fai and Cantwell, 1999; Hall and Ziedonis, 2001).

The recent acquisitions of the economics of knowledge, a new and fast rising area of empirical and theoretical investigation, have added new opportunities to exploit patent analysis, as a proper indicator to measure the real extent of the technological competence and hence of the innovativeness of firms. Next to the quantitative assessment of the stock and flows of patents, respectively, held and delivered to each firm, the composition of both the flow and the stock of patents of each firm, in terms of distribution across the existing technological and scientific fields, emerges as an important source of information and eventually assessment of the actual size and relevance of the innovations introduced by each firm (Granstrand, Patel and Pavitt, 1997).

The composition of the stock and flow of patents can be analysed in terms of distribution across the spectrum of technological and scientific fields identified by the patent offices and eventually standardized in the international statistical sources (Fai and Von Tunzelmann, 2001).

The dispersion of patents across scientific and technological fields can be considered a reliable measure of the technological competence of a firm. The wider is the dispersion and the smaller the concentration, the larger is the technological competence. The width of technological competence however can be the result of a variety of factors and processes included between the two extremes of business diversification and technological complexity (Fai, 2003).

The dispersion of the patents across the scientific and technological fields identified by the patent offices in fact can be an indicator of the attempts of a firm to diversify into different product markets. Technological diversification is a sign of eventual business diversification. Technological diversification can be the result of unexpected outcomes of research projects that have generated relevant knowledge in fields that are far away from the traditional scope of business activity of the firm. Technological diversification can be the effect of the general exposure of firms to a new general purpose technology – such as plastics and new information and communication technologies (Fai and Von Tunzelmann, 2001a).

Finally, technological diversification can an indicator of technological complexity, that is the variety of technological and scientific sources that is necessary to command in order to introduce a technological innovation in a given product market (Antonelli, 2003).

The scope of the analysis plays a crucial role in the interpretation of the results. The analysis of the distribution of patents across fields in a sample of firms that are heterogeneous in terms of product markets can yield useful insights about the role of technological diversification as an indicator of business diversification. The longitudinal analysis of a sample of firms can reveal important information about the role of general purpose technologies. The analysis of the dispersion of patents among firms that are homogeneous with respect to the product market can provide important information on the extent to which technological diversification is a measure of technological complexity and as such a good measure of the depth and relevance of the technological innovations being introduced by a firm.

The comparative analysis of the structure of proprietary knowledge at the firm level and the study of its intra-industrial variance, both in longitudinal and cross-sectional terms, can provide important elements to qualify the quantitative assessment of the size of the patents stocks and flows, usually considered as an indicator of the technological advance of a firm.

4.THE EMPIRICAL ANALYSIS.

This section of the paper is set to provide an empirical analysis of the evolution of technological complexity in the European automobile industry and to investigate the relationship between the structure of proprietary knowledge and the innovation performance of European car makers. In particular, we focus our research effort on a specific dimension of knowledge structure, namely its complexity.

Our operational definition of complexity is based on the patent documentation produced by different companies over the last seventeen years. Although the notion of complexity is becoming a relatively established concept in theoretical analysis, its empirical definition is still matter of debate among scholars. The concept has been made operational through different quantitative computations, ranging from the variance in patent classes that are used by Patent Offices to describe technological applications, the persistence of specific classes in a company's portfolio, the reference to non patent literature and cross-classes backward and forward citations. Obviously, each of the different definitions is apt to capture a different nuance of the complexity dimension and the obvious solution would be to aggregate different measure into one comprehensive figure. This solution, nevertheless, clashes with the problem of adding up different variables, that both dimensionally and conceptually differ greatly one from each other. Any attempt to weight and sum different measures of complexity would therefore end up in arbitrary choices that would seriously undermine the soundness of the empirical exercise. We have therefore opted for an empirical strategy based upon one selected operational definition of complexity, as the one described in the following.

As stated above, heterogeneity, i.e. the company's patent portfolio distribution in terms of patent classes[2], is a suitable way to measure how spread and differentiated is the technological domain that company's knowledge embraces. Though, the simple measurement of variance, for instance through the Herrfindhal index, implicitly assumes that the distance among classes is the same all through the patent portfolio, i.e. all technologies identified by a patent class are uniformly distributed over an hypothetical

[2] We here make reference to second level classes of the IPC classification.

technological space. On the contrary, common sense and experience would tell us that certain bits of technology are closer one each other than others. Therefore, any measure of variance should be implemented by taking into account the distances between patent classes.

The methodological problem shifts on the computation of a distance measure between classes, in a matrix form, that can be further on used to carry out a measure of portfolio variance that keeps into account distances among patent classes.

To our knowledge, no such attempt is to be found in the literature. We suggest that the most reliable way to define technological distance is to resort on backward citations. We argue that patents that share similar citations (in terms of cited patents) are similar, in the sense that they rely on the same sources of knowledge or they build on the innovations.

The notion of technological distance is therefore defined as a matrix whose generic element d_{ij} representing the distance between class i and class j is:

$$d_{ij} = 1 - \frac{n_{ij}}{N_{ij}}$$

where n_{ij} is the number of classes that are cited by both i and j while N_{ij} is the total number of classes cited by either i or j.

Such measure allows us to compute the overall distance of a company's portfolio, in the following form:

$$D = \frac{\sum_{z=1}^{P} \sum_{y=1}^{Y} d_{zy}}{2}$$

where d_{zy} is the distance of two generic individual patents drawn from a company's portfolio. D is therefore a weighted measure of differentiation that provides a fair account of the technological complexity of company's portfolio.

4.1 THE DATASET.

We used the information provided by the European Patent Office database in order to quantitatively evaluate the different degrees of complexity.

We have extracted and examined 10,884 patents from the EPODOS archive; patents were assigned to companies on the basis of applicant's and inventor's field, in a time window including years 1984-2001. Per each patent were able to retrieve basic data such as application date, applicant's name, inventor name, backward citations and reference IPC classes.

4.1.1. THE EVOLUTION OF THE EUROPEAN MARKET SHARES.

In order to assess the economic performance of car makers we organised a data set including yearly revenues, market share and production volumes.

The structure of the market, respectively in years 1984 and 2001, the beginning and end of our time period are reported in the following tables 1 and 2.

At the beginning of our observations, the structure of the European industry was the one described in the table above.

TABLE 1: Market structure in 1984

Volumes and market shares			
GROUP	TRADEMARK	VOLUME	MKTSHARE
FORD	FORD	1,295,800	12.80%
FIAT	FIAT/LANCIA	1,285,275	12.73%
VAG	VOLKSWAGEN/AUDI	1,220,534	12.09%
PSA	PEUGEOT/CITROEN	1,164,515	11.53%
GM	OPEL	1,113,962	11.03%
RENAULT	RENAULT	1,102,708	10.92%
BRITISH LEYLEND	ROVER/LAND ROVER/MINI	395,209	3.91%
DAIMLER-BENZ	MERCEDES & others	331,521	3.28%
BMW	B.M.W.	301,363	2.98%
VOLVO	VOLVO	237,865	2.36%
ALFA ROMEO	ALFA ROMEO	108,089	1.78%
SEAT	SEAT	153,623	1.52%
LADA	LADA	90,120	0.89%
SAAB	SAAB	62,796	0.62%
SKODA	SKODA	37,493	0.37%
PORCHE	PORCHE	19,518	0.19%
JAGUAR	JAGUAR	10,235	0.10%
Other*		1,093,404	10.83%
total		10,096,030	100.00%
*including Japanese, European and smaller European car makers			

Today, industry structure is far more complex and can be described as follows:

- B.M.W., presently owner of BMW and Mini trademarks;
- Volkswagen Group, includes Volkswagen, Rolls-Royce, Bentley, Audi, Lamborghini, Skoda and Seat trademarks;
- Daimler Chrysler, owning the Mercedes-Benz passenger car Group with the following trademarks: Mercedes-Benz, Smart (in 1998) and Maybach (in 1966); the Chrysler also belong to DaimlerChrysler with Chrysler, Jeep and Dodge trademarks;
- Renault, presently owning Rumenian Dacia and Korean Samsung Motors;
- PSA, originated in 1976 following the Cytroen – Peugeut merger, owning also the Talbot trademark;
- GME, General Motors Europe owning the following trademarks: Opel, Vauxhall, Holden, Saab, Buick and Chevrolet, plus ahres on Isuzu (49%), Subaru (20%) and Suzuchi (10%). Vauxhall Motor was acquired by GM in 1925, Opel in 1929.
- Ford Motor Company owning Ford, Mercury, Lincoln, Volvo, Jaguar, Land Rover, Aston Martin trademarks;
- FIAT Group, owning Fiat, Lancia, Alfa Romeo, Innocenti, Autobianchi, Maserati e Ferrari trademarks.

The result of such complex market structure reshaping is described in the following table 2, also reporting on market shares and production volumes.

TABLE 2: Market structure in 2002

Volumes of production and market share			
GROUP	TRADEMARK	VOLUME	MARKET SHARE
BMW	BMW	521.283	3,513
	MINI	27.793	0,187
	Total	549.076	3,701
DaimlerChrysler	Chrysler	76.198	0,514
	Jeep	21.485	0,145
	Mercedes	741.834	5,000
	Smart	104.148	0,702
	Other	106	0,001
	Total	943.782	6,361
FIAT	Alfa Romeo	202.307	1,364
	Fiat	1.067.521	7,195
	Iveco	21	0,000
	Lancia	148.983	1,004
	Other	3.252	0,002
	Total	1.422.084	9,585
FORD	Ford	1.309.366	8,825
	Jaguar	41.587	0,280
	Land Rover	73.479	0,495
	Volvo	223.345	1,505
	Other	843	0,006
	Total	1.648.614	11,112
GM	GM	8.793	0,059
	OPEL Vauxhall	1.516.628	10,222
	SAAB	73.383	0,495
	Total	1.598.804	10,776
PSA	Citroen	861.854	5,809
	Peugeot	1.279.994	8,627
	Total	2.141.848	14,436
RENAULT	Renault	1.576.004	10,622
ROVER	Rover	158.827	1,070
VW	Audi	545.954	3,680
	Seat	403.444	2,719
	Skoda	245.546	1,655
	Volkswagen	1.603.331	10,806
	Other	767	0,005
	Total	2.799.042	18,866
Other		1.198.739	13,471
TOTAL		**14.836.829**	**100,00**

The situation pictured in Table 2 is the result of the complex wave of corporate restructuring that has deeply changed the structure of the automotive market over the nineties.

Among the extremes, a complex story of mergers & acquisitions, hostile and friendly takeovers, and other corporate restructuring. We have traced such story year by year in order to be able to follow the evolution of industry structure and to precisely assess market shares and patent indicators all through the years.

4.1.2. TECHNOLOGICAL COMPLEXITY IN THE EUROPEAN AUTOMOBILE INDUSTRY.

The technological complexity of the European automobile industry has been increasing steadily in the second half of the XX century. Mechanical engineering had been the basis of the knowledge used in the automobile industry in the previous fifty years. The introduction of plastics in the late fifties and through the rest of the century marked the first strong departure from a strong concentration of the structure of proprietary knowledge. Eventually the dispersion of the technological basis increased sharply with the increasing role of electronics, avionics, and eventually new materials. The conduct of the largest European car makers is quite coherent: the portfolio of patents has been progressively changed with increasing levels of dispersion across scientific fields in the last years of the XX century. Yet relevant differences in the timing and composition of the process of technological diversification can be found among them. The German car makers took quickly the lead in the diversification of their technological portfolios with a sharp reduction of the share of patents in the mechanical engineering field and a sharp increase in the presence in the chemical fields. The French car makers exhibit a higher level of resilience in concentrating their patents in the engineering fields although the variance within the engineering fields increases steadily. The following table 3 illustrates the composition of the aggregate patent portfolio in the automotive industry between 1984-2001, in terms of technological composition.

TABLE 3: Technological composition of patent portfolios.

TECHNOLOGICAL DISTRIBUTION ACCROSS MACRO CLASSES (%)																			
	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	TOTAL
A	3.109	0.833	2.128	0.576	0.452	0.649	2.066	0.000	0.253	0.294	0.000	0.774	0.149	0.353	0.283	0.524	0.219	0.422	0.542
B	51.813	42.500	51.976	52.738	49.321	48.485	47.107	44.259	49.114	42.647	35.294	40.812	44.709	49.647	45.798	49.289	46.233	43.823	46.408
C	1.036	2.083	0.608	0.865	1.584	0.866	0.207	1.253	2.785	1.765	3.059	2.128	2.534	1.176	2.266	2.094	1.683	1.267	1.700
D	0.518	0.000	0.000	0.000	0.226	0.000	0.207	0.209	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.317	0.064
E	5.699	4.167	5.471	3.170	4.072	2.165	3.719	3.340	3.038	2.647	1.647	3.095	2.086	2.941	2.077	3.366	1.975	2.851	2.903
F	25.907	37.083	30.395	35.159	31.674	35.931	33.678	35.699	28.861	30.294	37.176	34.816	32.489	30.471	33.428	29.469	33.650	34.213	32.755
G	8.290	9.167	6.383	4.323	7.919	8.225	7.025	7.307	9.873	10.294	12.706	10.251	9.985	8.941	10.104	8.751	9.729	10.876	9.188
H	3.627	4.167	3.040	3.170	4.751	3.680	5.992	7.933	6.076	12.059	10.118	8.124	8.048	6.471	6.043	6.507	6.511	6.230	6.441
HF	**0.348**	**0.330**	**0.371**	**0.405**	**0.354**	**0.372**	**0.345**	**0.336**	**0.339**	**0.299**	**0.290**	**0.306**	**0.322**	**0.352**	**0.336**	**0.343**	**0.341**	**0.323**	**0.336**

A. HUMAN NECESSITIES; B. PERFORMING OPERATIONS; TRANSPORTING; C. CHEMISTRY; METALLURGY; D. TEXTILES; PAPER; E. FIXED CONSTRUCTIONS; F. MECHANICAL ENGINEERING; LIGHTING; HEATING; WEAPONS; BLASTING; G. PHYSICS; H. ELECTRICITY.

The evolution towards technological complexity in the automobile industry parallels a clear evolution in the distribution of the technological competence across the main European competitors.

We have preliminarily measured the degree of complexity by making reference to the concept of heterogeneity (variance) of a company's patent portfolio. This was evaluated using an Herfindhal measure of concentration of the patent applications in the International Patent Classification (IPC) scheme. We define $i \in I$ the specific technological class; it has to be stressed that the set I does not represent the totality of IPC classes since we restricted the analysis to the patent classes that are representative of car makers' portfolios. This means that we have excluded the classes that represent less than 0.5 in the aggregate car makers patent portfolio. In practice, (see appendix 2 for details) we have used the whole "F" and "B" classes, that altogether represent nearly 97 of the aggregate portfolio.

The following figure 4 provides a synthetic account of the evolution of the technological complexity of each of the European carmakers considered. The data show that the German manufacturers are the clear leaders in the race towards technological complexity: Daimler Benz its measure of complexity from 1.57 in 1984 to 2.45 in 2001. Opel follows with 2.02 in 2001 and BMW ranks third with 1.65. PSA, Renault and Volvo exhibit strong values in 2001, although their rate of increase is much weaker. Finally FIAT shows low levels of complexity and no dynamics, like Jaguar, Rover and Saab.

EVOLUTION OF COMPLEXITYs																		
Trademark / Year	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
BMW	1.01	1.03	1.05	1.07	1.10	1.10	1.12	1.11	1.17	1.21	1.25	1.22	1.27	1.41	1.50	1.49	1.63	1.65
DAIMLER BENZ	1.57	1.63	1.80	1.75	1.83	1.84	1.87	1.90	2.01	1.99	2.04	2.10	2.17	2.18	2.22	2.40	2.41	2.45
Gruppo Fiat	0.93	1.00	1.04	1.02	1.03	1.07	1.05	1.06	1.05	0.99	1.01	0.97	0.94	0.99	0.96	0.95	0.95	0.94
Gruppo VAG	0.76	0.80	0.83	1.01	0.90	0.94	0.94	1.02	1.05	1.10	1.17	1.11	1.06	1.20	1.28	1.28	1.30	1.25
Opel	1.04	1.07	1.00	1.04	1.10	1.12	1.25	1.20	1.10	1.21	1.42	1.19	1.21	1.32	1.38	1.99	1.96	2.02
PSA	1.31	1.33	1.38	1.30	1.34	1.48	1.41	1.55	1.56	1.50	1.64	1.73	1.71	1.64	1.68	1.74	1.58	1.62
RENAULT	0.94	1.02	1.03	1.06	1.10	1.19	1.14	1.11	1.18	1.16	1.18	1.34	1.35	1.35	1.30	1.40	1.48	1.48
JAGUAR	0.57	0.43	0.51	0.15	0.39	0.41	0.45	0.50	0.53	0.66	0.51	0.60	0.70	0.62	0.68	0.55	0.54	0.67
Rover Group	0.63	0.75	0.62	0.73	0.71	0.89	0.70	0.63	0.88	0.90	0.92	0.94	0.88	0.79	0.85	0.92	0.93	0.91
SAAB-SCANIA	0.71	0.75	0.63	0.69	0.71	0.59	0.70	0.76	0.74	0.75	0.77	0.78	0.80	0.90	0.91	0.9	0.99	0.92
VOLVO AB	1.11	1.10	1.11	1.20	1.17	1.40	1.20	1.21	1.22	1.24	1406	1.42	1.35	1.33	1.38	1.46	1.40	1.55

The decline of technological opportunities in mechanical engineering and the increasing role of the new technological fields such as plastics, electronics and avionics has profound effects on the management of the knowledge production. Learning is less and less able to contribute the general production of new knowledge. The investment of dedicated resources in science based activities and formal R&D emerges as a key factor.

The technological basis of the European carmakers became increasingly complex and in turn only the command of a complex knowledge base was able to provide the firms the flow of technological innovations necessary to retain appropriate market shares. The command of a diversified and increasingly complex knowledge base requires effective competencies and dedicated resources. The appreciation of the technological complexity is an important step towards the real understanding of the quality and relevance of the technological competence of the firms in this specific industry.

A few firms are able to engage in the process, while others fall behind (See table 5). The following figure 5 illustrates the technological market share in the period 1984-2001, i.e the relative share of patents owned by each single car maker over the total patent production in a given year of the 11 groups considered.

TECHNOLOGICAL MARKET SHARE																			
Trademark / Year	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	**Stock**
BMW	10.36	14.58	20.36	19.31	16.97	16.45	9.92	6.89	7.34	10.88	9.18	15.86	19.37	19.53	16.24	15.18	18.07	22.49	**15.98**
DAIMLER BENZ	2.07	1.25	3.34	4.90	11.31	11.47	15.08	15.66	19.49	15.29	21.65	19.15	26.38	26.00	31.63	25.73	19.75	17.32	**19.45**
Gruppo Fiat	15.54	20.00	18.24	16.14	21.27	17.97	19.42	14.61	19.75	22.35	19.76	19.54	17.88	11.41	5.29	5.31	4.90	5.17	**12.26**
Gruppo VAG	8.81	13.33	12.77	9.22	7.69	10.39	11.78	13.99	9.87	8.24	7.76	5.61	7.00	16.71	21.53	28.05	32.77	22.28	**17.54**
Opel	4.15	6.67	4.26	3.46	1.13	1.73	1.65	2.71	3.04	4.12	5.65	6.19	4.62	4.12	2.08	2.99	1.76	2.22	**3.11**
PSA	27.98	22.50	21.58	26.80	21.04	19.48	19.01	17.75	16.96	15.00	12.94	10.83	6.11	6.94	7.08	5.24	6.58	11.62	**12.00**
RENAULT	22.80	12.92	10.03	8.36	9.50	7.79	7.44	12.11	10.38	12.06	9.88	10.64	8.35	8.35	10.01	9.80	10.68	14.78	**10.46**
JAGUAR	0.52	1.25	0.61	1.15	2.49	4.33	2.89	1.25	2.53	1.76	1.41	0.39	0.30	0.12	0.28	0.45	0.37	0.32	**0.96**
Rover Group	1.55	1.67	0.30	1.73	0.90	1.95	2.07	1.88	1.77	2.35	1.65	4.64	2.09	1.41	2.17	2.77	1.83	0.21	**1.88**
SAAB-SCANIA	4.15	2.50	2.43	3.75	3.62	4.76	3.10	3.76	2.28	3.53	3.06	1.74	0.45	0.35	0.38	0.52	0.95	0.63	**1.70**
VOLVO AB	2.07	3.33	6.08	5.19	4.07	3.68	7.64	9.39	6.58	4.41	7.06	5.42	7.45	5.06	3.31	3.96	2.34	2.96	**4.66**

4.2. TECHNOLOGICAL COMPLEXITY AND MARKET SHARES.

This section presents the main empirical findings on the test of our hypothesis: the intensity of innovation activity, as measured by the flows of patent application and more specifically by the intrinsic characteristics of the knowledge produced and capitalised and in particular by its complexity, has exerted a strong effect on the evolution of the market shares of firms in the European car industry in the last years of the XX century.

We use a fixed effects panel data model to estimate the various effects that different dimensions of complexity are supposed to exert on company's economic performances. Furthermore, we are keen on gaining a better understanding of the internal relationship between different forms of knowledge (specifically in the dimension of complexity) and the intensity of patenting activity itself. The underlying hypothesis is that not only complexity produces its effect directly on economic performance but also indirectly through innovation intensity.

We have therefore tried to understand whether our measure of technological complexity, i.e. the distance weighted variance of the distribution of patents across the classes of the standard classification of the European Patent Office (EPO) can be used as an explanatory variable in a regression model where portfolio complexity (and its lagged covariates) and patent flows are the regressor and the evolution of market shares is used as dependent variables.

The data that are available for evaluating the economic performance are derived by our original data set that includes revenues and volumes of sales of single car makers over the period 1984-2002. As discussed in the introduction, for the purpose of our study, it has been evaluated that our units of observation should have been the groups rather than the single car makers. Using aggregate groups we have defined a measure of economic performance in the form of market shares of the single groups (*MKTSH*). It has to be noted that we are dealing with a rather ambiguous definition of relevant market, since the eleven groups that we are considering have different product mix and operate in different and unrelated markets. For this reason the aggregate measure of market share may result in a poor measure of economic performance. In consideration of this aspect, it is advisable to switch to a relative and more consistent measure of economic performance, the relative variation of market shares over two years:

$$\Delta MKTSH_t = \frac{MKTSH_t - MKTSH_{t-1}}{MKTSH_{t-a}}$$

Such variable has been used in the fixed effects panel model that we used to test whether there can be found any sign of correlation between our measure of complexity and economic performance.

$$\Delta MKTSH_{it} = \alpha_{it} + \beta_{1it} COMPL_{it} + \beta_{2it} NUMPAT_{it} + \beta_{3i} COMPL_{it} \bullet NUMPAT_{it} + \beta_{4it} COMPLT1_{it} + \beta_{5it} COMPLT2_{it} + \beta_{6it} NUMPATT1_{it} + \beta_{7it} NUMPATT2 + \varepsilon_{it}$$

In this model, the variables *COMPL, COMPLT1* and *COMPLT2* capture the measure of complexity (*D*) illustrated in paragraph 4.

The lagged variables *COMPLT1* and *COMPLT2* are introduced to keep into account the fact that there is a structural lag between the innovative effort and the patent application date. Regarding the structure of lags, it has to be stressed that market share does respond with some lag to the innovative effort, but that this latter is also reflected in the patent stock with some delay, thus resulting in an almost simultaneous effect on market share, if any.

The variables *NUMPAT, NUMPATT1* and *NUMPATT2* are defined as the number of patents applied for by the car maker respectively on the same year, one year earlier and two years earlier. In order to keep into account non linear effects we also regressed market share against the cross product between *COMPL* and *NUMPAT*.

Results of model estimation are summarised in the following table.

TABLE 3: Regression results

Multiple R2	0.8560
R2	0.7509
Corrected R2	0.6684
Standard error	0.0301
Observations	126

	Coeff	*Stat t*	*Significance*
Constant	0.16814	13.8639	0.000
β1	-0.0286	-1.3824	0.061
β2	0.0597	4.9165	0.001
β3	0.0069	6.8694	0.001
β4	0.1198	8.9001	0.007
β5	0.1155	14.3766	0.000
β6	0.1167	10.9566	0.000
β7	0.0049	11.0299	0.000

As expected, most of the variables used in the model are significant and show the expected sign. There is a lack of evidence that complexity exerts its effect simultaneously, but there is a strong evidence that one year and two years lagged variables have a positive and significant influence on market share.

Analogously, the variable *NUMPAT* is positive and significant both simultaneously and lagged. It indicates that the flow of patenting activity is able to explain the variations in market shares.

As expected, the coefficient β_3 is significant and positive, indicating that the combined effect of the size of the patent portfolio and of the variance of the portfolio produces a non linear effect and positive effect on market share. It has also to be noted that the effect is rather small in absolute terms.

5. CONCLUSIONS.

Technological complexity measures the variety of complementary and yet diverse competencies in different scientific and technological disciplines that are necessary to introduce effective and relevant technological innovations. The analysis of the composition of the portfolio of patents held by each firm in terms of distribution across the standard technological patent classes can provide important information about the conduct of the firms. The variance in the composition of the technological patents, within a sector, can become a useful indicator of technological complexity. Technological complexity qualifies and specifies quantitative indicators based upon patent counts. Such a more reliable and systemic indicator of technological advance of a firm in turn provides the opportunity to assess the relationship between technological advance and competitive advance in terms of changing market shares.

The rate of introduction of technological changes in the automobile industry no longer resides in mechanical engineering related competencies exclusively. The command of a variety of diverse technological disciplines is necessary in order to introduce effective technological innovations in the car industry. The role of learning by doing in the accumulation of technological competence is less and less relevant while science based research activities and intimate relations with the academic community play a much stronger role. Plastics, electronics, avionics, chemistry at large are nowadays as relevant as a variety of engineering branches. Technological complexity is a necessary condition in order to compete in the car industry, a market characterized by typical monopolistic competition based upon both relentless product innovation and aggressive price strategies based upon the continual introduction of cost-saving technological changes.

The empirical analysis of the evolution of the market in the European car industry in the last twenty years of the XX century has confirmed the strong and effective role of technological complexity, next to the number of patents, as an indicator of the relevance of technological innovations in explaining the changing distribution of markets shares.

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Appendix 1 – Stylized facts in the automotive sector.

- 1979, Chrysler Europe sells Simca, Talbot e Sunbeam;
- 1979, a joint venture between Rover and Honda is established, Honda owning 20 of Rover;
- 1982, merger between Volkswagen and Seat;
- 1982, Renault purchases Jeep trademark from American Motor Company;
- 1984, acquisition of Talbot by Peugeut;
- 1986, Rover Group is established, including Austin-Morris, Triumph, Jaguar, Land Rover, Range Rover and Mini;
- 1986, Fiat buys Alfa Romeo;
- 1986 Renault sells Jeep rademark to Chrysler;
- 1988, Fiat purchases Ferrari.
- 1988, British Aerospace buys Rover group from state-owned British Leyland;
- 1990, Saab Automobile AB becomes a 50 joint venture in General Motors Group, while the remaining 50 remains to Saab-Scania AB;
- 1990 Volkswagen purchases Skoda;
- 1990, Ford Motor Company purchases Jaguar;
- 1993, Chrysler sells Lamborghini;
- 1993, Bugatti (owned by Crhysler) purchases Lotus;
- 1993, Fiat purchases Macerati trademark;
- 1994 BMW buys 100 of Rover from British Aerospace Company and Honda;
- 1994, Ford Motor Company buys 100 of Aston Martin Lagonda;
- 1998, Lamborghini is bought by Audi;
- 1998, Volkswagen buys Rolls Royce and Bentley. Nevertheless, Rolls Royce trademark is bought by BMW. In the same year, Audi, buys Lamborghini;
- 1998, merger between Daimler-Benz Aktiengesellschaft and Chrysler Corporation;
- 1998, Renault buys 51 of Dacia;
- 1999, Ford buys Volvo Car. In the same year Volvo buys Scania;
- 1999 Renault buys 58 of Dacia, (92,7 in 2001);
- 2000, Ford buys BMW Land Rover and Range Rover;
- 2000; General Motors Corporation buys the remaining 50 of Saab;

- 2000, alliance between Fiat and General Motors: FIAT sells 20 against 5,1 of GM.