Evolutionary Pattern of Innovation and Product Life Cycle : Empirical Evidences form the Electric Motors Technology

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Evolutionary Pattern of Innovation and Product Life Cycle : Empirical Evidences form the Electric Motors Technology

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Abstract :

This paper aims to contribute to the analyse of the interdependencies between patterns of innovation and industry structure, by means of an evolutionary interpretation of an empirical case study - the Electric Motors technology - (EMT). The paper tries to link evolution of EMT during its life cycle to the industry's pattern of competition. This paper tries to show the main driving forces of the shift in the EMT pattern of innovation and to understand what factors determines the impacts of this shift in the industry organisation and structure. This empirical case study provides useful insights to explain why the evolution of several industries do not conform to the product life cycle (PLC) theory. It is argued that the existence of dominant designs does not impede the introduction of niche technologies in the market. Mature technologies can be renewed by technological innovation in niche technologies and changes in selection environment. The paper also shows that the impact of the innovation process in the industrial dynamics can change during the technology life cycle. The impact in the industrial dynamics vary according to the relative the market power of the specialised and dominant firms. In the case of the electric motors industry, the relative market power was determined by the combination of the following factors : the nature of the technology, the previous industrial structure and the evolution of the demand.

1 - Introduction

The electric motor technology (EMT) is a mature technology. It was introduced in the market at the end of the last century. The electrification of production processes has made of electric motors the main consuming technology for electricity in industrialised countries. Today, in the United States for example, electric motors account for 70% of the electricity demand in the industrial sector, and for about 50% of total electricity demand. The EMT is by far the most important technology for stationary motorisation. The motor population in the US was estimated to be about one billion motors in 1987 (EPRI, 1992). Every year millions of electric motors are sold to replace failed motors and for new applications, which represents a market of about 9 billions dollars in 1997 only in the US. For the European Community as a whole, the figures are not very different of the US. Electric motors are responsible for 60% of industrial electricity consumption and 43% of total demand(Energy Economist, 1996). The electric motor market was estimated to be $ 8,5 billions dollars in 1995. Therefore, electric motor construction is an important industrial segment today.

The EMT has been submitted to a standardisation process since the beginning of this century. However, we assist to a process of technological de-maturity recently with important impacts to the industry dynamics. This paper analyses the main technological and economic factors contributing to this renewing. It tries to show the main dynamics driving this process of technological renewing. In addition, we try to understand how this process of technological de-maturity impacts the structure of the industry using the framework of evolutionary theory of innovation.

Our analysis is based in two main evolutionary assumptions. First, it is argued that the existence of dominant designs does not impede the introduction of niche technologies in the market (Willinger and Zuscovitch, 1993 and Saviotti 1996). On the contrary, the enlargement of the technology's habitat by the diffusion of a dominant technology increases the probability for the emergence of alternative niche technologies. For this reason, standardisation of a dominant technology does not necessarily means the reduction of the opportunities to innovate. In addition, the progressive knowledge accumulation concerning the production and usage of the niche technologies can change its selection and diffusion probability. Therefore, mature technologies can be renewed by technological innovation in niche technologies and changes in selection environment. Secondly, it is assumed that the impact of innovation on the industry structure depends on the way firms learn and build their competencies and on the role of the innovations on the industry's process of concurrence. In other words, the impact depends if the innovation process concerns all industry's firms or only those specialised on niche markets.

This paper starts by reviewing the theoretical literature concerning the patterns of innovation during the technology life cycle, in order to explain how an evolutionary interpretation can be taken into consideration to analyse this question. Thereafter, the second section analyses the main features of the process of innovation in EMT. Finally, the third section tries to link the pattern of innovation with the dynamics of the electric motors industry, analysing the historical role of the technology in the process of competition.

2 - The Shifts in Technology Pattern of Innovation and Impacts for the Industry

Several evolutionary studies have shown that the evolution of technologies is framed by specific patterns of innovations. These patterns of innovation has been grasped by different concepts such as «technological regimes» (Nelson and Winter, 1982), «technological paradigms» (Dosi, 1982), «technological guideposts» (Sahal, 1985), or «dominant designs» (Abernathy and Utterback, 1978). These concepts present important similarities in their meaning and application. They suggest that technology evolution is influenced by the history of previous learning process due to the local and tacit character of knowledge accumulation and to the increasing adoption returns[1]. It is frequently suggested that shifts in technologies' pattern of innovation have profound impacts on the industry process of competition and, as a consequence, in the industry organisation and structure. However, these concepts have not addressed adequately the question of how the shift in the technology pattern of innovation takes place.

The technological ruptures that are at the origin of changes in established patterns of innovation have traditionally been seen as radical innovations developed mostly by new firms. Therefore, most of the literature has seen the ruptures in pattern of innovation as exogenous to the industry process of competition. Because of this belief, few studies have been interested to analyse how shifts in patterns of innovation take place. Nevertheless, a very important volume of research has been dedicated to the analyse of the impacts of the shifts of pattern of innovation for the industry structure. These studies have improved significantly the understanding of the factors driving the impacts of the process of innovation in the evolution of industry structure. However, important research questions remain unexplained, such as why the impacts of the process of innovation vary from industry to industry.

2.1 - The product life cycle theory

The PLC theory tried to determine the interaction between the technologies evolution and the industry organisation and structure. The most influential work on this field has been the research of Willian J. Abbernathy and James M. Utterback[2]. This theory claims that there is some regularities concerning the way technologies and industry organisation evolves. The basic assumption of TLC is that the locus of innovation moves progressively from product to process technology during the PLC (See figure 1).

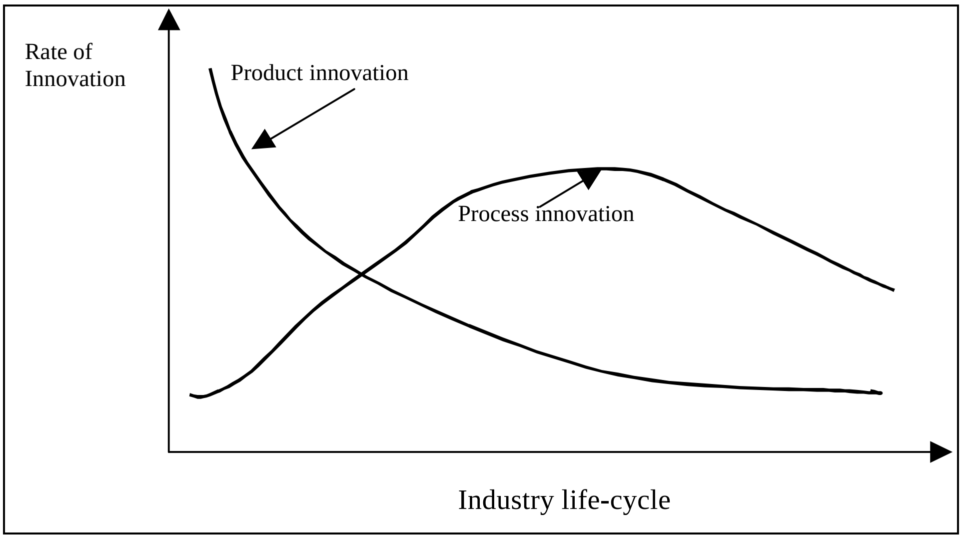
This pattern of technology evolution was associated to some regularities on the evolution of industrial organisation, notably concerning the pattern of firm's entry and exit (see figure 2). It is assumed that the number of producers is relatively small in the period of the introduction of a new product (stage I in figure 2). The risks associated to the pioneering strategy limit the number of firms in this beginning phase of technology development (in general one to three producers). In a second stage of the industry evolution, a growing number of firms will be disposed to enter in the industry, increasing sharply the product competition. A large number of product variants are introduced in the market as a result of the important opportunities of product innovation. In this phase, producers still faces substantial uncertainty about user preferences and the best technological ways to satisfy these preferences. The process of product competition is followed by a technological learning (from both producers and consumers sides), which reduces the uncertainties about the product technology. As a consequence, a *dominant design* emerges and the opportunities for product differentiation are depleted. The existence of dominant design contributes to reduce the risks of investing in costly production process technologies. As a result, firms will turn their technological strategy to the reduction of production costs by adopting more efficient process technologies. Competition based on the production process technologies will drive less efficient firms away from the industry (stage III).

[1] The main sources of increasing adoption returns are : the learning by using (the performance of the technology increases with its use) ; the positive network externalities (the utility of a technology for potential adopters increases with the enlargement in the number of users : telephone for example) ; scale economies (the product costs grows slower then the increase in production ; reputation effect (decrease of risk aversion by consumers) ; technology interrelations (diffusion allows a better access to complementary products and services, e.g. technical assistance, replacement parts, related infrastructure, etc.). See David and Foray (1995) and Foray (1989).

[2] See Abernathy & Utterback (1978) and Utterback (1994).

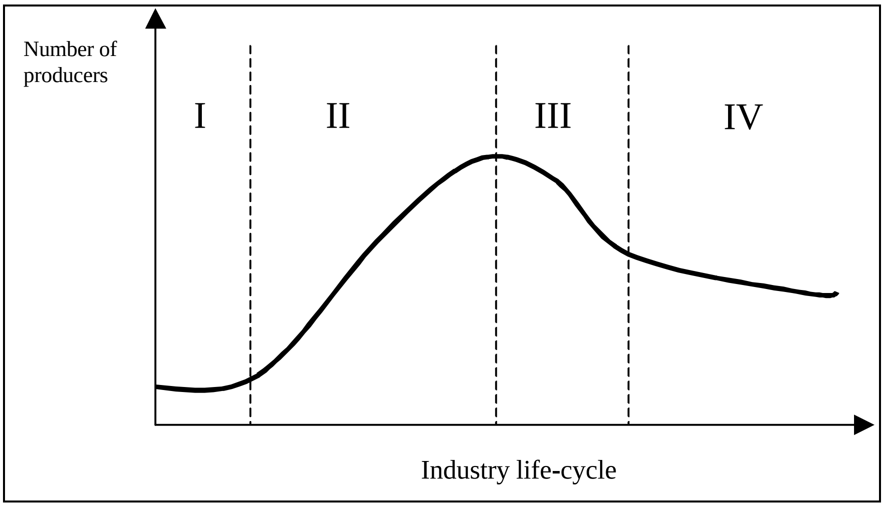
Finally, in the stage IV, the number of producers will stabilise at a certain number of firms, which have a minimum size to adopt efficient process technologies.

Figure 1 : Evolution of Innovation Effort in the Technology Life Cycle



Source : Utterback and Abernathy (1975).

Figure 2 : Evolution of number of producers



Source : Utterback and Abbernathy (1975).

Several studies have tried to verify empirically the main assumptions of the TLC theory. Gort and Klepper (1982) performed an extensive study with 46 different industries. This study analysed the pattern of firm's entry and exit for each the 46 industries. They produced an indicator for the rate of net entry in different stages of industry life cycle. This empirical analysis demonstrated that, in general, the evolution of industries structure respects the pattern stressed on PLC theory[3]. To test

[3] Utterback (1994) presents some case studies on several industries (typewriters, automobile, televisions and television tubes, transistors, electronic calculators, integrated circuits, winchester disk drives, and supercomputers), where the pattern of evolution of industry structure confirms the assumptions of TLC theory.

the hypothesis about the evolution of innovation effort, Gort and Klepper have measured the number of product innovation[4], the real percentage of decrease in the average price of new products and the number of patents issued in each of the new product categories.

The analysis of the pattern of technology evolution based on these measures has not been conclusive. The data on product innovation did not point to a decline in the rate of technical change. Similarly, the average rate of patenting did not diminish in time. However, the data has accorded in general with the hypothesis that in the beginning of TLC, technological change has a positive effect on entry and delays exit of less efficient producers. The analysis of product innovation showed that ...*major innovations occurring during the early stages of development of new product industries are of greater importance than those occurring later* (Gort and Klepper, 1982 : 650).

Several empirical case studies have inspired some scepticism regarding some of the assumptions of the PLC theory. The most important criticism regards the idea that the standardisation of product technology is a requirement for the adoption of efficient process technologies. As Klepper (1996) shows... « *the history of the automobile industry and others, such as tires and antibiotics, indicates that great improvements were made in the production process well before the emergence of any kind of dominant design* » (pg. 563). Furthermore, for some industries, like heavy electrical equipment, the innovation efforts are invariably concentrated in the product technology. In these cases, the rate of technical change does not allow the selection of a dominant design.

Klepper (1997) has also shown that some patterns of development of mature industries are not captured by the PLC theory. In this stage of the PLC, industry shakeouts has often been verified as a result of the renewal of product technological competition. In addition, the impacts of this technological renewal has not been the same from industry to industry. Empirical studies have shown that for some cases the incumbent firms have been the survivors of the industry's shakeouts. In some other cases, later entrants have been the survivors. Therefore, the empirical studies on the PLC call for further clarifications concerning the co-evolution of pattern of innovations and industry structure.

2.2 - The Characteristics of the Technology and the Pattern of Innovation

A significant part of the evolutionary literature concerning the impacts of the pattern of innovations in the evolution of industry structure has focused the attention on the characteristics of the technology and firms learning process (Winter, 1984 ; Nelson and Winter 1982 ; Malerba and Orsenigo,1993 ; 1997 ; Audretsch, 1997). This studies have shown that the pattern of innovation and their impacts on the industrial dynamics are very technology or sector specific, because innovative activity is a result of complex learning process. Firms and industries do not learn in the same way. The learning process is inherently cumulative and can generate specific competencies that determine what firms can do and what they can not do. "*On these grounds, one would expect to observe high degrees of diversity and variety in firms competencies, as well as relatively high degrees of persistence in their activities and performance. That is to say, firms appear to be able to build over time specific capabilities and assets which shelter them from selection and make them persistently "better" (or worse) than competitors"* Orsenigo (1995).

The way firms learn and their ability to build specific competencies is very important to determine the pattern of industrial dynamics. The entry in some sectors may be easier than others. These discrepancies are principally determined by the nature of the technology since they differ in terms of the characteristics of their knowledge base. The knowledge base can be primarily tacit, local and firm specific or rather codified and universal and thus relatively more easy to get access to. The concept

[4] Using a variety of sources, including the producers and expert advice.

Capitalism, Socialism and Democracy" (Schumpeter mark II). On the other hand, if the technology is presents high opportunity, low appropriability and low cumulativeness conditions, the pattern of innovation is associated to a technological regime characterised by low concentration of innovative activity, easy entry to the industry, new firms playing a major role in technological change. This technological regime was labelled "entrepreneurial" pattern since it converges to the schumpeterian vision of the "*The theory of Economic Development*" (Schumpeter mark I).

Even though important empirical evidences confirm the influence of the type of technology on the industry dynamics, this approach neglects fundamental questions for the PLC theory. If we examine this approach dynamically, we can ask the question if the characteristics of the technology - in terms of appropriability, cumulativeness and opportunities - can vary during PLC. If so, industries could change their technological regime during the PLC. Furthermore, what are the factors driving the changes in technology characteristics ? Does the industry organisation and structure have any influence on the evolution of these characteristics ? If this is the case, other factors have to be analysed to determine the impacts of the innovations on the evolution of industry structure.

In our view, in order to answer these questions and to identify the additional factors playing a role in the interplay of innovations and industrial dynamics, two fundamental questions the should be addressed : how does the shift in the technology's pattern of innovation takes place ? How innovations affects the process of concurrence in the industry ? These questions have been neglected by most studies concerning the process of innovation and industrial dynamics. Some recent evolutionary studies have presented valuable insights to explain the process driving the changes in patterns of innovation and their consequences. These studies explain the technical change taking into account the interdependence between the technological innovation and the evolution of the selection environment.

2.3 - Evolutionary Interpretation of the Shifts in Pattern of Innovation

More recently, new approaches on the evolutionary dynamics of technological evolution have contributed to explain how the shifts of patterns of innovation take place. These approaches try to explain the technical change taking into account the interdependence between the technological evolution and selection environment. Two dimensions of analysis are central: the process of technological differentiation (creation of technological variety) and the process of selection by the technological standardisation and the concentration of the innovation process in some specific technological options.

An important evolutionary hypothesis is the fact that firms try to differentiate themselves in the process of concurrence, searching for temporary monopolies. As illustrates Saviotti (1996), «*Firms deliberately seek to differentiate themselves from rivals through a multitude of types of product and process innovations. This process contains random elements but it is also shaped by the environment in which firms operate. Firms deliberately design this innovation to adapt to their external environment and sometimes to adapt the environment to themselves.* In the level of product technologies firms compete for consumers' requirements in terms of technological services. Therefore, as the competition to supply a specific technological service augments, firms will have stronger incentives to differentiate their products in order to specialise in market segments with less concurrence. Firms can use several strategies to differentiate their products. They can either offer an improved product that offers basically the same technological service or they can offer a new product that offers a new technological service. In the first case the improved product will replace an old existing technology. In the later case the specialisation in new market niches will increase the technological variety.

The niche theory in biology proposes that the rate of development of new species i.e., the rate of increase of variety, depends directly on the number of pre-existing species. In other words, the number of possible niches depends on the size of the habitat (May,1973). This theory has inspired a model of technological evolution based on replicator dynamics (Saviotti and Mani, 1995 and Saviotti, 1996), where the rate of creation of new technological populations is proportional to the size of pre-existing population. This model uses the scope of the technology, in terms of the volume of its' service characteristics space, as a proxy of the size of pre-existing population. Therefore, the number of niches in a technology population is expected to be proportional to the range of services it can perform (Frenken et al., 1999b).

From this niche theory approach we can derive that the existence of dominant designs does not impede the introduction of niche technologies in the market. On the contrary, the enlargement of the technology's habitat by the diffusion of a dominant standardised technology and the expansion of the range of services it can supply increases the probability for the emergence of alternative niche technologies. For this reason, standardisation of a dominant technology does not necessarily means the reduction of the opportunities to innovate.

Based on the niche theory approach, Willinger and Zuscovitch (1993) tried to explain how the changes in the pattern of innovation take place. They showed that the changes in niche technologies and in the selection environment are a gradual process of innovation. Technological paradigms are built on three different phases of technological development. In the pre-paradigmatic phase, new technologies are adopted in niche markets in the border of an established paradigm. New technologies are adopted because the established paradigm has decreasing returns in some of the niche markets. In these situations, alternative technological options can be better adapted in spite of their incipient development. The adoption of new technological options in niche markets allows for the improvement of these technologies due to learning-by-doing effects and the increasing adoption returns.

As the new technology reaches satisfactory performance as compared to the established paradigm and it will acquire the status of a radical innovation. At this point, the new technology arrives at the auto-organisation phase of its development. The progressive accumulation of a knowledge base concerning the production and usage of the new technology option will change its selection and diffusion probability. Finally, if the learning process and the technical potential of the new technology are big enough to overcome the irreversibility of the established paradigm, a shift in the technological paradigm can take place. The new technology becomes a new standard to solve specific technical problems and a different research agenda is embraced.

This evolutionary approach has important implications for the analysis of the impacts of the shifts of pattern of innovations in industry dynamics. The first important implication concerns the fact that the technology evolution is endogenous to the industry process of concurrence. Therefore, the impacts of shifts in pattern of innovation on the industry dynamics will depends on how evolves the process of concurrence in industry. Considering the case of the shift in the pattern of innovation in a mature technology, the competition associated to the "new product technology" will generally not concern all firms in a first moment. Two independent processes of competition will take place in industry at this moment. Some innovative firms will dispute the niche markets for the "new product" and the dominant firms will dispute the large market for the traditional product. As the new product became the dominant market, the process of competition can change, and all firms can be concerned by the new product technology. At this moment, industry can face a shakeout process, a lot of firms exiting the industry by bankrupts, fusion and acquisitions.

3 - The Evolution of the Electric Motors Technology

The EMT is a relatively old technology. The first few electric motors were introduced in the market in the 1870s. The diffusion of EMT as the dominant technology for the stationary motorisation followed the diffusion of the electricity. Already in 1939, electric motors were responsible for 89% of all motorisation installed capacity in industry in the US[5]. Since the first years of this century, the motors' dominant designs have been selected, and the innovation of these designs had been most incremental. Three types of design were selected and passed through a process of standardisation: the Direct Current - (DC) motors, the induction motors (Alternative Current -AC) and the Synchronous motors (AC). Roughly, these classic motors designs have a similar technical structure. However, the induction motor is by far the most important type of motor. More than 90% of integral motor applications (higher than 1 kW) employ the induction motor. In the fractional applications (less then 1 kW), the induction motors are also the most used type of motor.

After the standardisation of the classic motor technologies in the beginning of this century, continuous incremental innovation has taken place. Most of innovation concerned to the reduction of motor cost of production and the extension of its application domain. The number of different types of electric motor applications has increased continuously as a result of the expansion of the technological variety in the economy[6]. Given the expansion of electric motor's habitat, some niche markets have been created allowing the development of some alternative electric motors technologies. In other words, the classic motor technologies were not suitable for certain types new applications. One important alternative technology is the Permanent Magnet - (PM) motors. The development of improved Permanent Magnet materials[7] in the 1950s allowed the construction of new types of electric motors without the cooper windings in the stator or in the rotor, using permanent magnet instead. These motors are produced since the 1960s, especially for very small power application. Another important innovation was the development of the electronic Variable

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[5] Cf. Rosenberg (1982).

[6] Saviotti (1991) has showed that the increased variety of technologies and artefacts is one of the most important features of the evolution of economic system. Departing from Pasinetti's model of economic growth and structural change, Saviotti showed that an increased variety is a necessary condition for the employment of economic resources in the long term. Indeed, the number of technologies with which EMT interacts has unquestionably increased both in the level of motor production and application. See also Saviotti (1996).

[7] The permanent-magnet materials are those that, once magnetised, retain a substantial portion of that magnetisation even in the presence of opposing magnetic fields. Permanent magnetics underlie many technologies that are key to modern society, like electric motors, loudspeakers, and head actuators in hard-disk drives, microwave devices in telecommunications, data storage systems and imaging systems based on nuclear magnetic resonance.

Speed Drives - (VSD). These artefacts replaces mechanical techniques for control of motors speed. They are capable to control motors torque and speed to adapt the motors' service to the requirements of the load. Between 50 to 60 percent of motors' industrial applications requires some kind of speed and/or torque control[8].

3.1 - The evolution of the technological variety

We can verify the evolutionary dynamics driving the shift of the pattern of innovation analysing both processes of technological standardisation and differentiation. The process of standardisation is associated to the selection of a dominant design, and the process of technological differentiation to the introduction of niche technology in the market (Foray, 1989 and 1996). The analysis of the evolution of the technological variety can give us good indications of both processes of technological standardisation and differentiation. Some evolutionary studies have developed appropriate methods to measure the technological variety based on the «characteristics representation methodology» (Saviotti and Metcalfe, 1984; Sahal, 1985 and Saviotti 1996). This methodology defines the technology in terms of its technical and service characteristics. The first describe the characteristics of the technology's design and internal structure and the former the services it can produce. Once we describe the whole technological population or a representative sample of this population by its characteristics, we can apply appropriate methodologies to measure the technological variety.

3.1.1 - Variety Measures

The estimation of variety in a population described by its characteristics is a complex methodological problem. Two types of measures have been applied in empirical studies according to the type of available data. The first type is the entropy measure, which is very much used in information theory to measure the level of uncertainty concerning the position of one entity within a distribution of probabilities. Therefore, if the probability distribution is perfect, we have a maximal uncertainty to find one specific entity, which means that we have maximal entropy. This same logic can be applied to measure the degree of uncertainty or variety in a distribution of products. The entropy measure is given by the following formula:

$$(1) \qquad H(X_1) = c \sum_{i=1}^{A} p_i \log(1/p_i) \qquad (i=1,\dots,A)$$

Where:

X_1 is the product dimension represented by one type of characteristic;

p_i is the relative frequency of products classified in class i;

A is the total number of classes along the dimension X_1.

This type of measure can be used for technological populations described by discrete classes, i.e. is described by characteristics such as type of design, type of electric current etc. Is the population is described by many types of characteristics, we can apply the entropy measure for multivariate frequency distribution, given by the following formula:

[8] See Almeida and Fonceca (1997).

$$(2)\quad H(X_1, X_2, ...) = \sum_{i=1}^{A}\sum_{j=1}^{B} ... p_{ij....} \log(1/p_{ij....}) \qquad (i=1,...,A;\ j=1,...,B;...)$$

Where, X_1, X_2, ...Xn are the different characteristics represented. The most important limitation of the entropy statistics is the fact that it can not be directly applied for continuous data, such as motor power in kW, motor speed in rpm etc. In order to do so, it is necessary to take into consideration the type of distribution of these data, which complicates very much the analysis. Alternative methods have been developed in order to measure the variety considering the continuous data. The Weitzman's measure of diversity is specially adapted for this type of measurements (Weitzman, 1992 and Frenken et al. 1999a). This measure was developed with the intention to measure de degree of dissimilarity between two members of a population, where the measure of distance has to satisfy the conditions as follows:

$d(x, y) \geq 0$

$d(x, x) = 0$

$d(x, y) = d(y, x)$

Where x and y stands for different members of a population (x should not be confused with the characteristics of the member which is describes by X_1, X_2 ...Xn). The Weitzman variety for a set S of elements is given by the following diversity function:

$$(3)\qquad V(S) = \max_{y \in S} (V(S\backslash y) + d(S\backslash y, y))$$

According to this function, the variety of one set is given by the overall maximum of the distance from one member to its nearest neighbour, in addition to the variety of the population without this member. The solution of this function needs recursive operations, which augment exponentially in number according to the number of elements in the set (see Frenken et al. 1999a and b for details).

The main difference between the entropy and Weitzman measures of variety is the fact that the former considers the relative frequency of elements and the latter the distance among them. These measures can produce complementary indicators of the technological variety as the entropy measure can be applied for the discrete data and the Weitzman measure to the continuous ones.

3.1.2 - Variety measurements for the Electric Motors Technology

We have analysed the evolution of the technological variety in EMT using the entropy and Weitzman statistics. We have built a database of a representative sample of electric motors population for five different periods: 1900, 1921, 1935, 1950 and 1995 in order to make these measurements. This database totalled about 3071 different electric motor models. These periods were chosen because of practical reasons. These were the years where we could gather an extensive sample of catalogues. For each period, we tried to set up catalogues which were representative of all different types of motors available. This database included the main motor's technical and service characteristics as follows:

Table 1
Characteristics selected to represent the electric motors technology

Variable	**nature**	**classes / units of measure**
1. Nominal power	continuous	kW
2. voltage	continuous	Volts
3. speed	continuous	rpm
4. weight	continuous	Kg
5. efficiency	continuous	%
6. type of current	discrete	AC (1), DC (0)
7. type of material	discrete	with (1) or without permanents magnets (0)
8. type of armature	discrete	open (0) closed (1)
8. type of commutation	discrete	with (1) or without (0) commutator

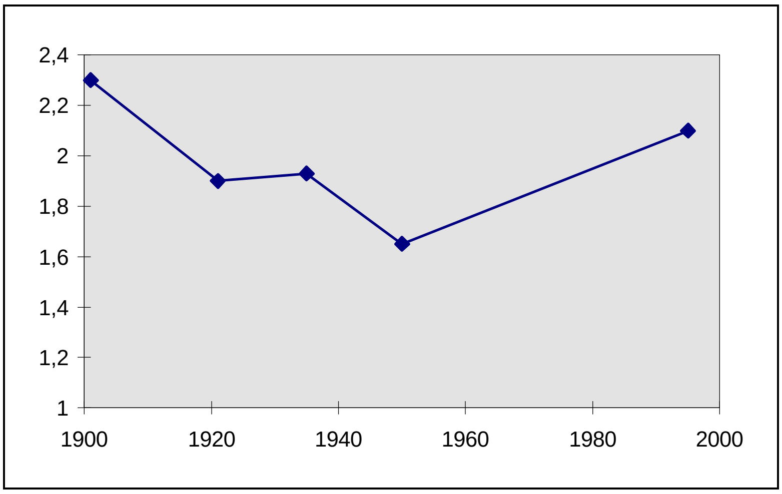
The entropy of discrete product characteristics and the Weitzman measure of the continuous product characteristics have been calculated. The entropy statistics shows that the variety of electric motors population decreased from the beginning of the century and 1950s and started to increase since then. The Weitzman measures confirms this trend and also suggest that the technological variety today is greater then it was in the beginning of the century. The initial decrease of the variety of EMT is related to the process of standardisation of the technology by the adoption of a limited number of patterns of design. After the 1950s, the process of technological differentiation has been more important then the process of standardisation. This fact can be explained by the enlargement of motor's habitat, measured by the range of services the motors can provide. The variables that have contributed the most to the enlargement of motors’ range of services were the speed and power range. In 1995, the motor catalogues cover a much larger power and speed ranges as compared to the previous periods. The power and speed maximums were 500 kW and 3000 rpm in 1950, and increased to 1500 kW and to 8000 rpm today.

The development of new technologies and artefacts that uses electric motor as a source of motorisation (for example, computers, servomechanisms, machine tools, domestic appliances, etc.) has required the extension of motor construction possibilities, mainly in terms of power and speed, and the increase in complexity of motors technical functions. Several technical functions have been added to EMT, such as the enlargement of speed and torque’s variability, the control of rotor position, and the power factor correction, etc. These new types of applications have induced and oriented the innovation process in EMT, and allowed the development of several technological options for niche markets.

The new types of applications can be seen as a source of «demand pull» to the process of innovation. On the other hand, some new important general technologies opened a large innovation potential for EMT. The main "technological push" has been the developments of electronics and material technologies. Here, it is important to remark that these general technologies have been mostly «technological spill-overs» since they have not been developed for application in EMT exclusively.

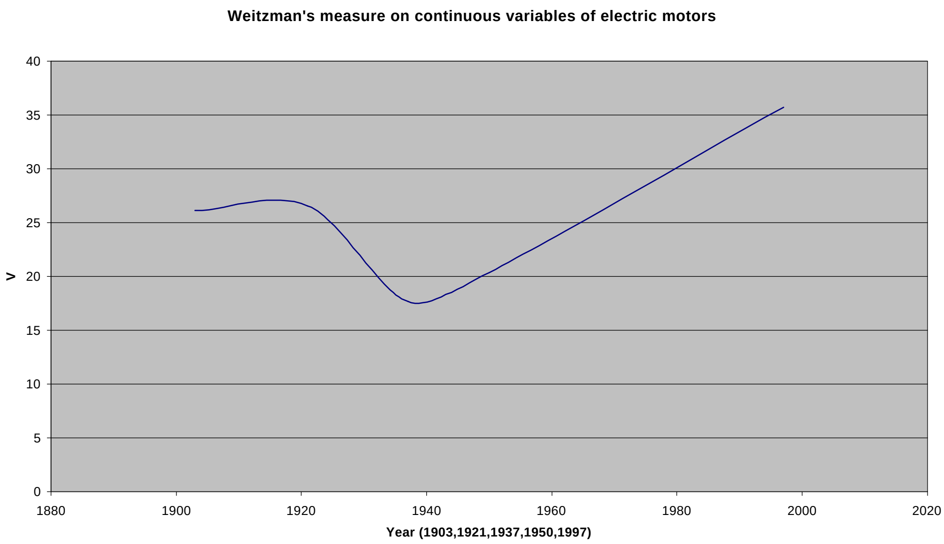
Figure 3

Entropy of discrete variable of EMT



Source: Own elaboration

Figure 4



Source: Own elaboration

3.2 - The development and evolution of motor niche technologies

The product characteristics analysis shows that the selection and standardisation of some dominant designs has cohabited for a long time with differentiation process in the niche markets. In fact, even though dominant designs have been selected since the first decades of this century, the standardisation of these models has not impeded the expansion of the technological variety in motor population. The introduction of radical innovations on the materials and the electronic technologies has contributed to the development of important new technological options. The variety measurements reflect this fact as the measures for 1995 shows a burst in the technology differentiation process. These innovations are renewing the importance of product innovations in the electric motors industry, as they open the perspective of a future technological competition.

3.2.1 - The innovations on Variable Speed Drives

The technological progress in electronics allowed the development of Power Electronics Technology. This technology concerns the power conversion between the electricity network and the applications. It embraces electronic artefacts used for electricity conversion and modulation in order to obtain controlled voltage and frequency. There are a large number of applications for the power electronics in the electricity system, however the must important application is the control and adaptation of the electricity supplied to electric motors, in accordance with their load curve.

The development of power electronics revolutionised the control of any type of machine that uses electric motors, as it allowed the ease integration of the computer technologies in the command of the machines. The integration of computer technology opened the path of technological evolution by the aggregation of artificial intelligence to machines and processes. The power electronics made possible the development and diffusion of electronic controlled machines[9] and processes automation technologies.

The possibility of ease modulation of electricity frequency made possible the use of new types of electric motors, which were already known but not used because of the lack of adequate command technologies. Some examples of new developments are the Step by Step motor, the Variable Reluctance Motors and the Electronic Commutated Motor. The enlargement of the possibilities for motors' speed variation by the use of VSDs had a major role in the development of new applications for electric motors. Before the development of VSD, the speed variation was limited to 5000 rpm with DC motor technologies. Today, VSD allows a speed variation between 0 and 20.000 rpm in a power range that goes up to 10 MW.

Given the great variety of application possibilities of VSDs, there is a large range of product lines available in the market place. Every year, new VSDs generations are introduced in the market. The speed of technical change in this technology has indeed intensified in the last 5 years. Before 1988, 13 generations of VSD were introduced in the French market. Today, in average 15 generations are introduced in this market each year. New product generation is developed every 2 to 4 years.

Until 1995, the VSD were produced disassociated from electric motors. They were build by specialised firms or electric motors' manufacturers, and were sold only separately from motors. Since 1995, some large motor producers such as Siemens and ABB developed an induction motor model, where the VSD is integrated in the motor design. These motors are produced only in power levels up to 10 kW. However, this innovation inaugurated a technological trend of considering the VSDs as component of EMT. Even though between 50 to 60% of motor applications require any kind of motor controls, today the diffusion of VSDs covers only structural applications, which represent about 5% of all total applications. The structural applications are those where the control of electric motors are indispensable to the machine's technical service[10]. The main obstacle for the diffusion of VSDs is their price[11].

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[9] Numerically controlled machine tools and robots.

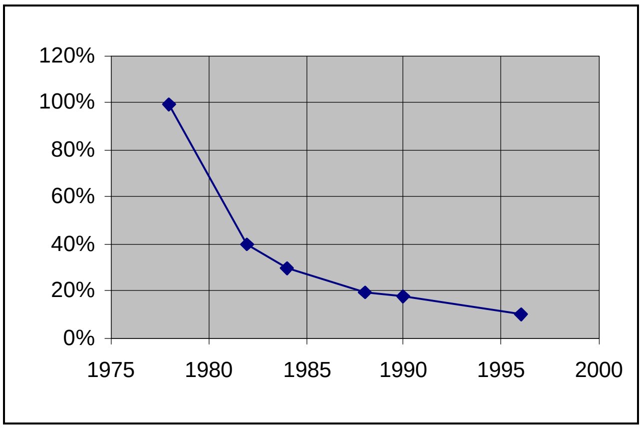
[10] For instance, paper machines, machines tools, steel laminations machines, electric cars and trains, just to mention a few.

[11] There is a huge potential for energy conservation associated to the diffusion of VSDs. When speed variation is required, the use of VSDs instead of mechanical technologies (resistance, throat valves, etc.) can result in 20 to 40% of energy savings. In the European Community, the potential savings were estimated to be between 5% (47,7 TWh) and 15% (128,2 TWh) of total electricity consumption in the industrial and tertiary sectors by 2010. Cf. Almeida and Fonceca (1997).

In the United States, the price of VSD has decreased by 10% per year in the last 10 years (see figure 5). However, the price of VSDs is still higher than motors' price. For small power applications, VSDs can cost 3 times more than the motor itself. Therefore, innovation process has still a lot to contribute to VSD's price reduction and to the overall diffusion of this technology.

Figure 5

Evolution of the price of VSDs (15 KVA)



Source: Chauprade (1989) and Hense (1996).

3.2.2 - The evolution of the Permanent Magnet motors

In the beginning of 1950s, the development by Philips Co. of permanent magnet materials based on barium-strontium (BaSrFe - Ferrite) allowed the general application of this type of material for the construction of small electric motors[12]. In the last 20 years, permanent magnet materials have been submitted to revolutionary technological improvements. The development of rare earth PM materials in the 1970s, based on alloy of Samarium (SmCo) and, more recently, on Neodymium and Barium (NdFeB), have revolutionised the hard magnetic materials. Rare earth PM motors with very high magnetic performance have been developed to be used in servomechanisms (robots and machine-tools). These motors can have six times superior torque as compared to a classic motor with similar weight. Similarly, rare earth PM motors can be 3 to 20% more energy efficient than classic motors, depending on the power level. However, this revolutionary performance is expensive and the diffusion of these motors is restricted to the niche markets. The Samarium, Neodmium and Barium materials are not abundant in nature and require important industrial processing for their use as permanent magnets.

The technological jumps in Permanent Magnet materials allowed the adoption of EMT in a very large number of new applications. The size of the market for fractional electric motors has already surpass the market of integral motors, due to the development of an impressive number of household appliances and machines motorised by small PM electric motors. For instance, the average number of small motors embodied in household appliances in European Community is estimated in 20[13]. In sophisticated car models, the number of small motors can exceed a hundred[14]. In the industrial

[12] See Leprince-Ringuet (1991).

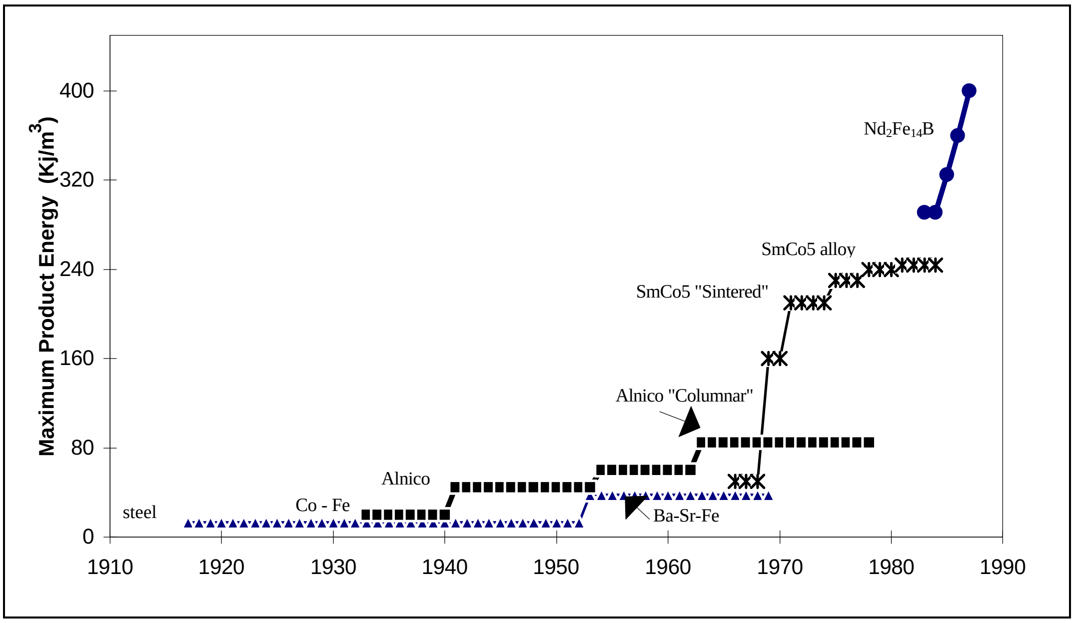
[13] Verdun (1994).

[14] See Kenjo (1991) and Verdun (1994).

sector, all numeric control machines and robots represent new types of applications for electric motors.

Figure 6

Evolution of Permanent Magnet Materials



Source: Long & Grandjean (1991).

The main type of PM motors for the industrial sector is the Electronic Commutated Motor. This motor uses inversors and encoders to make current commutation, which means the integration of power electronics in motor design. The ECM motors can have speed variation between 0 and 10,000 rpm and today are produced in the power range of 0.1 to 20 kW. The Permanent Magnet motors are not directly in concurrence with induction motors so far. However, the Electronic Commutated Motor have an important technical potential and can be viewed as a potential concurrent for induction motors, since they present several technological advantages. The higher energy efficiency is the most important advantage, but there are other advantages such as higher torque and power-to-weight ratio. Currently, these motors are used in servomechanisms, where the high level of power-to-weight ratio and the torque are important requirements and can justify the higher prices of these motors. The high torque density and the increase in power-to-weight ratio allow for important reduction in motor size and for the ease speed variation. Given the higher torque level of PM motors, today we have important research programs on vehicle motorisation oriented to this type of motor[15].

4 - The Electric Motors Industry Dynamics

The electric motor industry is born as a segment of the electric equipments industry. In other words, the main motor makers where also producers of equipments for electricity generation, transport and distribution. However, progressively many exclusive motor makers entered this industry, by the acquisition of licenses or the specialisation in niche markets. Given the technological variety, a large number of firms are present in this market. The electric motors industry has been traditionally

[15] See Douglas (1992).

organised in several market segments, according to the pattern of firm's specialisation. The most important segment is the standardised motors market, controlled by few large firms (generalists) capable to exploit the scale economies in motors production and distribution. The others markets segments are the special motors market, the VSD market, and the fractional power motors market (less then one kW).

The special motor markets concern the tailor made motors for specific applications. This market segment concerns the motors that requires a lot of «engineering» for their conception, and whose volume of production is too small to attract of the large motor makers. The VSD segment was traditionally dominated by specialised firms. The core competencies of these firms were based on ability to follow the rapid pace of technical change in the field of power electronics and control, and to provide engineering services for the VSD's installation and maintenance. Finally, the market segment of fractional motors has two specificities that allow the specialisation of a large number of firms. The first is the large technological variety as compared to the standardised integral motors (more than 1 kW). The second is the fact that most of fractional motors are sold directly to the original equipment manufacturers (OEMs). Therefore, the scale economies in the commercialisation (distribution networks) are less important. A lot of firms have entered this market segment with the strategy of specialisation and co-operation with specific types of OEMs. The bulk of motor producers are present in these last 3 market segments.

Since most of innovative activities was concentrated in niche technologies, the small firms had an important role in the traditional pattern of innovation. As far as EMT is concerned, the large generalist firms were most involved with innovations in process technologies, since the competition in standardised motors segment is done mainly by price differentiation. Therefore, the overall pattern of innovation was traditionally associated to entrepreneurial technological regime (Orsenigo, 1995 and Malerba and Orsenigo, 1997). In this case, a large share of innovations was carried by new firms, who launch new enterprises concerning product technologies.

Some important changes in the selection environment of electric motors industry contributed to change its dominant pattern of innovative activities. Because of the changes in the selection environment, the importance of niche technologies increased substantially, provoking important shifts in the firm's technological specialisation.

4.1 - The main changes in the industry selection environment

Since the second half of the 1980s, important transformations in the selection environment of the electric motor industry have taken place. The changes in the selection environment was the result of the combination of the two following factors: deep modification in the structure of the electric materials oligopoly at the international level; and the consolidation of the trend for the adoption of mechatronics[16] in the production processes, represented by the automation and control technologies.

4.1.1 - The re-organisation of the electric equipment industry

The electric equipment industry comprises the firms that produce equipments for electricity generation, transport, distribution and, certain types of equipment for electricity use, such as electric motors. This industry has experienced a process of oligopolisation since the beginning of this century. The pattern of competition in the electric equipment industry was traditionally dictated by the firms' capacity to exploit scale and scope economies in product development, production and commercialisation (Salaun, 1995 et Passer 1953). After the Second World War, the electric

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[16] Mechatronics is a term used to describe the integration of mechanical and electronic engineering.

equipment industry entered a period of rapid expansion due to the consolidation of the electric industry in the industrialised world. Governments have systematically favoured the rise of domestic electric equipment industries, adopting protectionist policies. The development of the electric industry as state owned utilities allowed for a close co-operation with national electric equipment industries. This environment made possible the development of several national oligopolies in the electric equipment industry.

The context of competition in the electric equipments industry has profoundly changed since the second half of the 1980s. The growth rate of national markets for electric equipment materials slowed dramatically as the electric industry entered its mature phase. Simultaneously, the protectionist policies have been progressively ceased by the liberalisation of the electric industry and of the international trade. The introduction of competition in the electricity industry followed by the privatisation in some countries (United Kingdom for instance) provoked the end of the traditional pattern of co-operation between the electricity and electric equipment industries. As a consequence, the rivalry has increased in the segments of electric equipments for electricity generation and transport. This fact combined with slowing pace of market expansion has provoked an important shakeout in the oligopoly of electric equipment industry.

The shakeout in the electric equipment industry started with the fusion of the Swiss group BBC with its Swedish rival Asea in 1987. This fusion formed the biggest multinational group in the electric equipment industry with a turnover of $ 15 billions at that moment. This operation was followed by several important operations of fusion and acquisitions, such as the creation of Gec-Alsthom, as a result of the fusion of the British group GEC with its French counterpart Alsthom. In the US, an important rearrangement has progressively taken place in the oligopoly of the electric equipment industry. General Electric has restructured its activities emphasising the electric equipment industry. Westinghouse, on the contrary, has chosen to abandon this industrial sector.

The shakeout in the electric equipment industry has produced the rise of few large groups capable to operate at the global scale[17]. The reinforcing of the oligopolisation at the international level has produced important impacts for electric motors industry. Even though the main market motivation for this shakeout came from the market of equipments for electricity generation and transport, other markets segments has endured important consequences. The international groups have taken advantage of their size to reinforce their presence in the electrical industrial apparatus segment. These groups have strengthened their presence in the market of « turnkey plants ». Given the scale and scope economies in the R&D, these groups are able raise important competitiveness, on the development of industrial automation and control technologies. In other words, the large firms of the international oligopoly have been very successful in the development of technological capabilities concerning the fusion of electronic and electric technologies.

4.1.2 - The consolidation of a new techno-economic paradigm in the industry

Nelson and Winter (1977) pointed the existence of certain natural technological trajectories, which are common to a very large number of technologies and sectors. They highlight the fact that a large number of technological innovations on the production processes were motivated by the exploitation of economies of scale and of progressive mechanisation of production processes. The development and diffusion of very general technologies, as the electricity and the chemical technologies followed this pattern of innovation. Nelson’s and Winter's idea of general natural trajectories was developed

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[17] These groups are ABB (Switzerland/Sweden), Siemens (Germany), General Electric (US), Hitashi (Japan), Mitsubishi (Japan) and Toshiba (Japan), Fuji Electric (Japan) Gec-Alsthom (United Kingdom/France), and Schneider Electric (France).

further by Perez (1983,1985), who associated these trajectories to Schumpeterian long waves of economic development and Kondratief economic cycles[18]. Therefore, for each wave of economic development, Perez has identified specific pattern of technical change linked to the development of very pervasive technologies. Perez has named this very general pattern of innovation techno-economic paradigm. It can be seen as set of common-sense guidelines for engineers and managers concerning technological and investment decisions that are so pervasive that can affect almost all sectors of the economy[19].

Perez has shown that the current techno-economical paradigm is characterised by the diffusion of microelectronics technologies in all levels of production process, in order to improve productivity by process automation and control. The power electronics technology is a key technology for the new techno-economic paradigm, since it is applied to the control of process and machines, by the modulation of the power supplied to the electric motors. This technology embraces all the electronic artefacts used for electricity conversion and modulation in order to obtain controlled voltage and frequency.

The automation of production process is possible by the adoption of electronic controlled machines[20] that are partially or totally commanded by Computer Based-Manufacture Systems, i. e. the Computer-Aided Design (CAD) and the Computer-Aided Manufacture (CAM) systems. The CAD is the application of computer technology to the elaboration and modification of product design, while the CAM is the use of computers to manage and control the operations of a manufacturing facility. These systems allow the integration and treatment of all information required to design, produce and deliver the product. The most visible benefit of the adoption of these systems is the labour savings at the production stage. These savings are possible by the elimination of the majority of jobs related to the machines operation and surveillance. Additionally, this techno-economical paradigm is characterised by a substitution of labour by robots, notably in the mechanical industry. In the last 10 years, the robot market in Japan, for instance, has expanded 17% per year (Jornal da Ciencia, 1997).

Besides the labour savings, there are several other benefits of the automation of the production process, such as improvement in the co-ordination, the flexibility and the efficiency of production process. The adoption of Computer Based-Manufacture Systems also improves the efficiency of the production process via the decrease of necessary volume of inventories and the reduction of investment in unfinished products in various stages of completion (lower the process waste). It is thus clear that the adoption of electronic controlled machines commanded by Computer Based-Manufacture Systems is a general direction of technical change in industrial processes[21]. This general direction of technical change has important implication for the pattern of innovation in the EMT. The robots and machines electronically controlled are important applications for the PM motors and VSDs. Therefore, the market for these types of motor technology is expanding at a rapid path nowadays.

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[18] In the Schumpeterian theory, the development of waves of technical and economic development are due to the introduction and diffusion of innovation in clusters. Schumpeter explained the existence of clusters of innovation by the event of agglomeration process following important innovations. The development of new important technologies tend to give rise to imitation processes and complementary innovations, which contributes to concentrate in time the event of innovations.

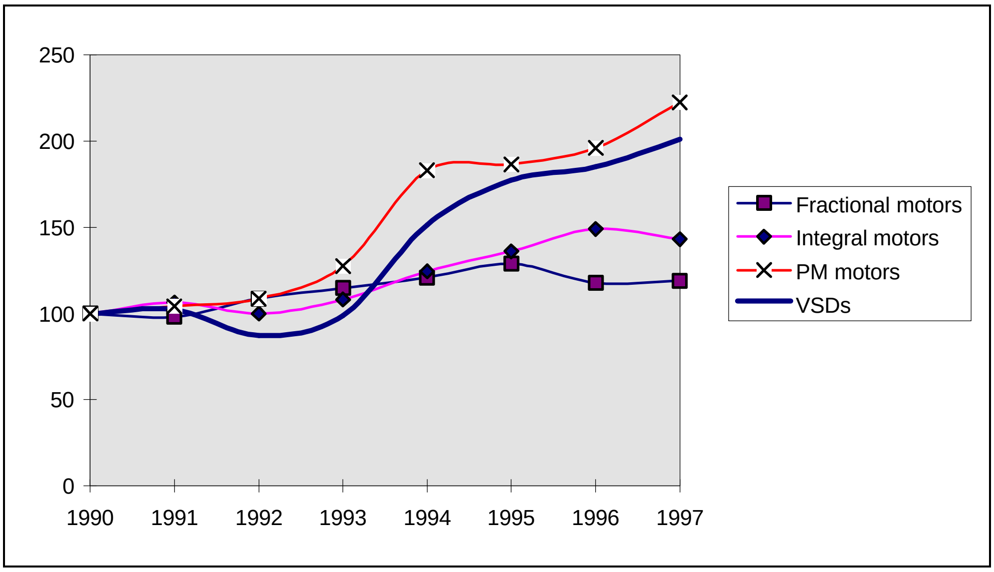
[19] Cf. Freeman (1994) and Freeman and Perez (1986).

[20] Numerically controlled machine tools and robots.

[21] A recent study has shown a rapid pace of diffusion of this type of technology in France (Sessi,1997). For instance, the rate of adoption numeric control machines in 1997 was 43% of total industrial firms. Additionally, about 20% of industrial firms have already adopted electronic control and command systems for regulation and supervision of processes ; and 15% of firms have adopted any type of robots.

Figure 7

The evolution of the main types of motors market segments



Source: Bureau of the Census (1998).

4.2 - The impacts of the changes in selection environment in the electric motors pattern of concurrence

The changes in the organisation of the electric equipment industry and in the shape of the demand for EMT have profoundly impacted the pattern of concurrence in the electric motor industry. As we mention, this pattern of concurrence was traditionally characterised by the specialisation of a large number of firms in niche markets (fractional motors, VSDs and special motors), the larger generalist firms being concentrated in the standardised motors market. However, the increasing diffusion of industrial automation and control technologies required new technological strategies of main electric motor makers. As the importance of the niche technology increased, most of generalist firms decided to “attack” these market segments.

The first generalist firms to enter these segments were those from the electric equipments international oligopoly. These firms are using their financial and technological market power to diversify their product lines and enter the niche markets. In fact, these firms are taking advantage of the commercial complementarity between the electric motor market and other markets, such as plant engineering and construction, to produce and commercialise a diversified range of products for motorisation. Moreover, the importance of “turnkey plants” market has increased significantly in the last ten years as a result of the consolidation of the new technological techno-economic paradigm in the industry. Therefore, when a very diversified group builds a complete industrial plant, it can integrate its own equipments, such as standardised and PM motors, VSDs, process control and command systems etc. The “turnkey plants” is a very important market channel since the market for motor replacement is very much influenced by the market of new motors[22].

The competitive strategy of the generalist firms of the international oligopoly was followed by the reaction of the most important independent motor makers. These firms have also tried to enlarge their range of product and services in order to exploit the scope economies at the technological and

[22] Motor market surveys in the USA showed that 52% of industrial clients seeking replacement motors bought the same brand and model as the failed motor. Another one third of buyers procured the same brand (see DOE,1993 and almeida, 1998).

commercialisation levels, in order to face the competition of the large groups of the international oligopoly in the electric equipment industry. In addition, these firms have tried to reach a critical size to exploit scale and scope economies in technology generation. As a result, we assist a trend to the constitution of large industrial groups in the electric motors industry. Several independent electric motors groups with relevance at the international level have been created in the last 10 years. These groups have been formed by means of fusion and acquisition operations[23]. We would not be accurate if we impute the reshaping of the industrial organisation of electric motor industry only to technological factors. The recent trend of trade liberalisation at the international level has also contributed to the intensification of the competition and industry concentration[24].

In this light, the recent trend of mergers in the electric motors industry can be understood as a strategy to enlarge the range of competencies, in order to gain competitiveness in a new pattern of concurrence. This pattern is characterised by the exploitation of scale and scope economies in the production and commercialisation of motorisation technology.

4.3 - The evolution of the industry structure and organisation

We have examined the changes in the pattern of concurrence in the electric motor industry analysing the historical data from the US Department of Commerce concerning electric motors industry. We have verified that even thought the EMT constitutes a mature technology, the number of firms in the market has always increased between 1947 and 1992. During this period, the development of new niche technologies allowed for the net entry of new firms in this industry. Therefore, during this period the entrepreneurial pattern of innovation has been predominant in the electric motors industry. In order words, the expansion of the technological variety was mainly associated to the development of niche markets, where the majority of firms have specialised.

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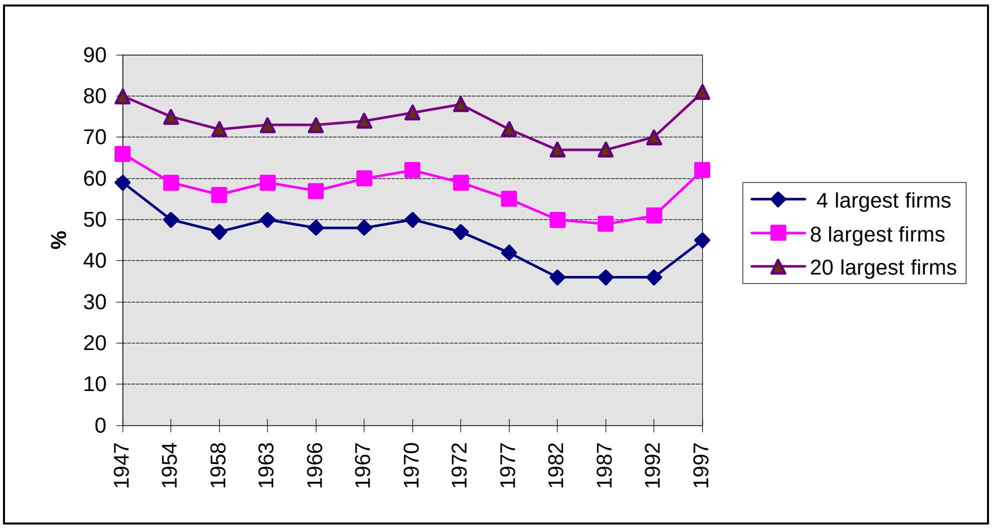
[23] The most clear example of this trend in France was the merger of Leroy Somer with Emerson Electric in 1990. Leroy Somer is the market leader in French standard motors market with 50% of market share. Leroy Somer has justified this merger by the need to enlarge their product lines in order to compete with other big European groups (especially ABB and Siemens).

[24] The main independent electric motor groups are the Emerson Electric ($ 12,3 billions of receipts in 1997), Rockwell Automation ($ 4,5 billions) and Magnetek ($ 1,2 billions) from the US ; BTR ($ 7,8 billions) from the UK and TECO Electric ($ 1,2 billions) from Taiwan.

Figure 8

The evolution of Market Share of largest firms in the USA



Source: US Bureau of the Census

As we can see in the figure 8, the industrial concentration has decreased considerably during the 1970s and the first half of the 1980s. This industrial de-concentration coincides with the period of the development of the niche markets for VSDs and most of PM motors. Since the second half of 1980s, we see a new trend for the industrial concentration in the US[25]. This trend can be associated to the new pattern of concurrence where the generalist firms try to assimilate former niche markets and technologies. In fact, the correlation between the changes in the number of firms and the rate of differentiation has radically changed after 1992. The number of firms has been reduced simultaneously to the increase in the innovation activity. Therefore, we can say that recent trend to the concentration of the motor industry motivated by the renovation of the importance of the competition in product technology.

Given these changes in the firms' specialisation we can argue that a new pattern of innovation has emerged in the EMT. Since the large established firms are now engaged in a competition by the differentiation of product motor technologies, the routinized technological regime became dominant. We can expect that accumulation of innovative capabilities by the established firms will contributes to reinforce the industry concentration.

4.4 - The consolidation of a new pattern of innovative activities

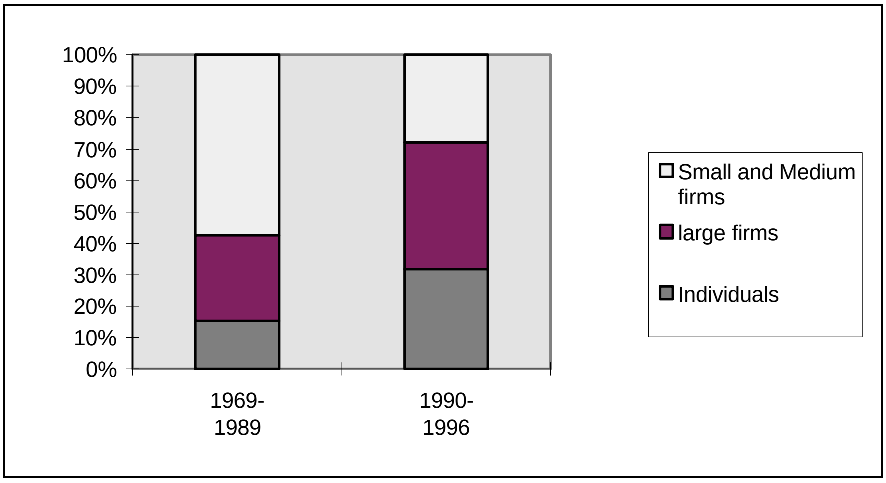
The analysis of patent statistics concerning the EMT confirms the changes in the pattern of innovation in the electric motors industry. These statistics shows that the large firms have taken the leadership in the R&D efforts in the EMT. The small and medium firms were the main authors of patents during the period of 1969 and 1989. This figure has completely changed in the 1990s, as now

[25] The trend of industrial concentration is definitely not a singularity of the US. In the beginning of 1980s, there were 150 independent motor producers in the European market. Today, five large producers control 66% of the motor market, and only twelve producers have a significant market share. These five larger motor producers are also important VSDs and PM motor producers. See Buysse (1996).

large firms are the most important patents' authors (see figure 9). In addition, the majority of the patents today concern new types of motors design (mainly PM motors) control technologies (VSDs). Therefore, the alternative motors technologies are in the centre of the process of competition in electric motors industry.

Figure 9

Share of patent deposits by type of agent



Source: US Patent and Trademark Office (1997) and the author

The fact that the large firms became the most important actors in the process of innovation can not be only explained by the characteristics of motor technology. In fact, important additional factors have contributed to this concentration of the innovative effort. The most important factor was the changes in the characteristics of the demand and in the organisation of the electric equipment industry, that contributed to increase the market power of large firms. The market power is associated to large firms ability to exploit scale and scope economies, not only in technology creation, but also in product commercialisation. The selection environment in the electric motors industry changed, entailing an important transformation of the process of concurrence in this industry.

The changes in the pattern of innovation have also embraced the rhythm of innovation. As the product technology came to the centre of the process of concurrence, firms' innovation efforts has increased substantially. In the last two decades, the research efforts regarding the electrical machine technology[26] in the US, Japan and European Community has jumped from $ 2.4 billion, between 1973-77, to $ 10.7 billion in the period of 1988-1992. Consequently, the number of patents registered in American Department of Patents has doubled between 1970 and 1995.

The pattern of innovation in EMT has change radically in the last 20 years. The EMT experienced a progressive process of de-maturation. Initially this change concerned niche technologies and specialised firms. However, the expansion of the niche markets and the transformation of the pattern of concurrence in the oligopoly of electric materials, brought former motors' niche technologies to the centre of the process of competition. Therefore, the product technology became one of the main determinants of firms' competitiveness. As the alternative motor technologies came to the centre of the innovation process in EMT, we can expect that the knowledge accumulation will engender an

[26] Mainly electric motors, generators and transformers.

important improvement in the efficiency of these technological options, which can lead to a new dominant technological trajectory in the evolution of EMT.

5 - Conclusions

The analysis of the evolution of the EMT has made clear important evolutionary stylised facts considering the changing on the pattern of innovation. Our empirical case has shown that the change in the pattern of innovation was not due to a process of innovation exogenous to the industry process of competition. In fact, we have shown that this change was progressive. For a long time, the introduction of important product innovations was limited to the niche markets. The adoption of alternative technologies in niche market contributed to the entry of new innovative firms, improving the knowledge base concerning these technologies. As these technologies improved their efficiency the importance of the niche market increased substantially.

We have shown that an important modification in the selection environment changed the pattern of competition in the electric motors industry. At this moment, the dominant firms were obliged to acquire new competencies related to the ancient niche technologies. In order to compete in this new selection environment, the main motor manufacturers are trying to produce a complete range of products for motorisation. Acquisitions and fusion were one of the main instruments to build technological core competencies. Therefore, the change in the pattern of innovation was the main driving force of the shakeout in the structure and organisation of the electric motors industry.

Our empirical case study has shown that the impact of the innovation process in the industrial dynamics can change during the technology life cycle. In fact, this impact depends both on the way firms learn and build their competencies and on the role of technology in the process of concurrence. In the case of EMT, for a long time the very innovative niche markets concerned only specialised firms. During this period, the innovation process engendered a net entry in the industry. On the other hand, when these same technologies attracted the attention of large established firms, the impact of the innovation process in the industry dynamics was the contrary. We assist to a recent trend of concentration of the electric motors industry. Large firms have been more successful in the new selection environment, as they are able to exploit scale and scope economies in technology generation and product commercialisation.

This empirical case study have shown that the understanding of the impact of the innovation process in the industry dynamics requires a detailed analysis not only of the characteristics of the technology, but also of the role of the innovations in the process of competition. The empirical evidences from the EMT shows that the shifts in the industry pattern of innovation are progressive and endogenous to the industry process of competition. The impact of product innovations in the industry dynamics can change in PLC, as these innovation may concern specialised or all firms in the industry.

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