Basic propositions for the study of the technological innovation process in the firm

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Abstract

This paper deals with the characteristics of two basic elements for the study of innovation in the firm: the concept of technological innovation, which is defined as a flow magnitude; and the concept of technology, which is defined as a stock magnitude. The technological innovation process is characterized by: being of a continuous nature; being path dependent; being irreversible and being affected by uncertainty. Technology, as the main product of this innovation, has the properties of knowledge and is characterized by: having a large tacit component; being difficult to transfer; being assimilated by accumulation; and being partially appropriable. These characteristics are articulated in a series of propositions that could contribute to the establishment of a consistent ground for the study of the technological innovation management.

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1. Introduction

Over the past few years, technological innovation management has become one of the most attractive and promising areas of study in the field of management. This fact is confirmed by the following developments:

- an increasing number of scholars have oriented their research towards this area;
- each year there are new scientific journals specializing in the study of innovation phenomena (currently, there are more than 50); and
- the consolidation of various academic associations, such as IAMOT and PICMET.

However, the academia does not yet have a solid theoretical base for the study of innovation management. This deficiency is particularly apparent in the coexistence of radically different methods of approach and the absence of a commonly accepted and precise terminology.

This paper puts forward a series of propositions that could contribute to the definition of a consistent basis for the study of the technological innovation process in the firm. To this end, the following section makes some terminological clarifications regarding two key concepts for the study of innovation phenomena:

(1) technological innovation, which is defined as a flow magnitude; and
(2) technology, which is defined as a stock magnitude.

Then, in sections 3 and 4 the main characteristics of these two concepts are identified and discussed. To conclude, section 5 articulates all the propositions.

2. Technology and the technological innovation process

The concepts used in the study of innovation phenomena are not usually precisely defined. There is a proliferation of terms and definition that often do not coincide with one another. The absence of a commonly used vocabulary in innovation management studies is such that the terms "innovation" and "technology" are often used interchangeably to signify the same idea. For instance, certain manuals on the study of the technological innovation process in companies refer to the subject matter in the title as "innovation management" (Afuah, 1998; Cozijnsen and Vrakking, 1993; Howells, 2003; Tidd *et al.*, 2001; Tushman and Anderson, 1997). Others, however, prefer to use "technology management" (Betz, 1993; Dussauge *et al.*, 1992;

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Gaynor, 1996; Harrison and Samson, 2001; Horwitch, 1986; Teece, 2003). Still others use both terms as in "management of technology and innovation" (Burgelman *et al.*, 2003; Levy, 1997; Narayanan, 2001; Rastogi, 1996) or "management of technological innovation" (Betz, 1998; Ettlie, 2000; Dogson, 2000; Roberts, 1987; Twiss, 1986).

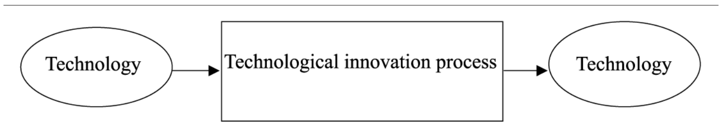
Such terminological inconsistencies could be considered trivial were it not for the fact that there is an important underlying problem behind them: the confusion of two different concepts. The technological innovation process, which is a flow magnitude, is one thing; technology, which is a stock magnitude (see Figure 1) is something else altogether. When the two terms are used interchangeably, no distinction is made between the process of generating and disseminating new technologies (technological innovation process) and the volume of technology available at a given time (technology). In order to clarify these ideas, a few terminological points are made below with regard to these two concepts.

2.1. The technological innovation process

In this paper, the term "technological innovation" is used to refer to the process through which technological advances are produced. The innovation process includes a set of activities that contribute to increase the capacity to produce new goods and services (product innovations) or to implement new forms of production (process innovations). Therefore, the concept of technological innovation is associated with the idea of a flow – generation, application, dissemination – of technologies.

Sociologists, historians and economists usually use other terms interchangeably when talking about the innovation process, such as: technological change, technical progress, technological development or simply innovation. Traditionally, industrial economists break down the process of technological innovation into a sequence consisting of three phases: invention, innovation and diffusion. Furthermore, in a great deal of research, due to the availability of statistical data on research and development (R&D) spending, technological innovation is identified with research (pure and applied) and technological development.

Figure 1 The process of technological innovation



The same terms have been used in management literature, when dealing with the technological innovation process. Recently, however, a change in orientation has taken palace and other concepts are beginning to be used such as: "organizational learning" (Argyris and Schön, 1996), "knowledge creation" (Nonaka and Takeuchi, 1995), "routine creation" (Nelson and Winter, 1982), "asset accumulation" (Dierickx and Cool, 1989), "core competency development" (Henne and Sanchez, 1996) and "dynamic capability development" (Teece *et al.*, 1997). All of these terms describe the flow of the generation of new knowledge within organizations, and therefore refer to phenomena that are analogous to the technological innovation process.

In fact, the concepts of learning and knowledge creation are often used to describe the innovation process: "Companies innovate through a constant learning process through which they generate new technological knowledge" (Nonaka and Takeuchi, 1995, p. 3). Furthermore, it has been recognized that the innovation process in companies basically consists of the development of new routines, since "the conversion of an organization's activity into a routine constitutes the main form of storage of that organization's specific operational knowledge" (Nelson and Winter, 1982, p. 99). The innovation process has also been associated with the creation of core competencies (Henne and Sanchez, 1996) and with the development of dynamic capabilities (Teece *et al.*, 1997).

In light of the above considerations, the innovation process in the firm could be defined as follows:

P1. Technological innovation in companies is a learning process through which a flow of new knowledge competencies and capabilities is generated.

2.2. Technology

The term "technology" is used to refer to the stock of knowledge -whether codified or tacit-about the set of all industrial techniques available at a given time. It should be kept in mind that technology plays a twofold role in the technological innovation process: it is both the output of the innovation process as well as its principal input (Figure 1). The literature uses different terms to refer to the output of the innovation process, such as innovation[1], discovery, invention, technological knowledge, etc. All of them also signify stock magnitudes.

In the field of management, the term "technology" has been used in various senses. An explicit definition of the term is often avoided: "technology is a key competitive factor that needs no definition". In some cases, restrictive

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definitions have been established – "technology is applied science" – which conceive technology as a body of scientific and technical knowledge that is needed to innovate (Betz, 1993, p. 8; Friar and Horwitch, 1986, p. 144). According to this view, technology lies between scientific knowledge and the productive activities derived from it. Thus understood, the function of technology is limited exclusively to the improvement and/or creation of new processes, products and services.

Traditionally, the word "technology" has been used extensively to describe the production process (Woodward, 1965) and even other activities carried out by business. In line with this tradition, today, there is a tendency to establish broad definitions of technology, equating it with the specific way in which a task is carried out in a given organization (Gaynor, 1996, p. 1.7). This conception goes beyond the restrictive idea of technology that associates it exclusively with the results of R&D work. Indeed, technology "in some cases, is a specific process; for example, a chemical process, which produces a specific product. In this case it is difficult to separate the product from the technology. In more general terms, technology can mean a manufacturing process such as continuous iron casting. Here, the technology may be separated from the product. The cash management account is another example of a process that is clearly separable from the product. New data processing technologies have made the implementation of this account possible. We may think of technology in broader terms, looking at it as the way a company has of doing business or carrying out a task" (Foster, 1986, p. 36).

This broad view of technology is consistent with the consideration of the innovation process as a learning process, a process for the creation of new knowledge or for the development of new routines. In this way, the concept of technology would be akin to the concepts of knowledge or routine, which are stock magnitudes.

Technology can also be seen from the perspective of core competencies and dynamic capabilities. In fact, technology is nothing more than a competency insofar as "a competency can be defined as a unique combination of knowledge and skills that allow the generation of a series of profile innovations" (Chiesa and Barbeschi, 1994, p. 293). The concept of technology can also be associated with dynamic capability since "dynamic capabilities reflect the ability of an organization to obtain new and innovative forms of competitive advantage" (Teece *et al.*, 1997, p. 516).

Table I shows the relationships that exist among technological innovation, technology and other stock and flow concepts used in the study of innovation phenomena.

In light of the above considerations, technology at the company level can be defined as follows:

P2. Technology is the output and the principal input of the innovation process and reflects the volume of knowledge, competencies and capabilities that the company possesses at a given moment in time.

3. Characteristics of the technological innovation process

Some recent works (Shilling, 1998; Teece, 1996) have expressed concern with identifying the characteristics of the technological innovation process. The characteristics they mention are remarkably influenced by research carried out by evolutionary economists (Arthur *et al.*, 1987; David, 1985; Dosi, 1982, 1988; Nelson and Winter, 1982; Rosenberg, 1976) and are consistent with assumptions regarding the nature of the firm by authors using a resource-based view (Barney, 1991; Peteraf, 1993; Wernerfelt, 1984). They agree that the most relevant characteristics of the technological innovation process are being:

- of a continuous nature;
- path dependent;
- irreversible; and
- affected by uncertainty.

Let us now examine each of these characteristics.

3.1. Continuity

The essence of the technological innovation process is the accumulation of knowledge over time. The increase in the volume of knowledge is produced through the different creative mechanisms associated with the different modes of learning such as:

- learning derived from R&D activities or "learning before doing" (Pisano, 1997);
- "learning by doing", which arises spontaneously in the production process (Arrow, 1962a);
- "learning by using" which arises from observing the different ways in which clients use the company's products (Rosenberg, 1982); and
- "learning by failing" derived from analyzing erroneous decisions made by top managers (Maidique and Zirger, 1985).

Such modes of learning, especially the last three, have a clearly incremental character insofar as they generate a continuous flow of new technological knowledge.

Traditionally, greater importance has been given to R&D than to other modes of learning.

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Table I Terms used in the study of innovation phenomena

Flow magnitudes	**Stock magnitudes**
Technological innovation process (transformation)	Technology (input/output)
Terms that describe the flow of the generation of new technological knowledge at macro and micro level	Terms that represent the volume of technological knowledge available at a given time at macro and micro level
Macro level: society, economic system, industry	
Innovation (process)	Innovation (product)
Invention (process)	Invention (product)
Technological change/technological progress	Invent
Technical change/technical progress	Discovery
Invention-innovation-diffusion	Science
R&D	Technique
Basic research	
Applied research	
Technological development	
Micro level: firm	
Learning	Knowledge
Knowledge creation	Routine
Creating routines	Strategic asset
Asset accumulation	Core competence
Core competencies development	Dynamic capability
Dynamic capabilities development	Routine

This "has served, in many basic aspects, more to obscure rather than to clarify the technological innovation process" (Rosenberg, 1976, p. 90). Indeed, overestimating the role played by R&D, distorts the way in which the flow of technological knowledge increases and materializes in new products and processes.

It has been found that the economic impact of continuous improvement and small incremental innovations is greater than that of certain innovations considered to be radical. In fact, companies dedicate around 80 percent of their innovation efforts to improving existing products and just 20 percent to the development of new ones (Rosenberg, 1996).

Some technology historians (Rosenberg, 1982; Basalla, 1988) have pointed to the possibility that most innovations considered to be radical – the railway system, electric lighting, etc. – are just more powerful manifestations of the accumulation of small changes which confer a certain continuous character to the innovation process. Some even come to question the very existence of radical innovations (Basalla, 1988).

In general terms, the idea of technological innovation as a continuous process is consistent with other concepts used in the field of management. Continuous improvement (Imai, 1987), technological trees or clusters (GEST, 1986), the knowledge creation spiral (Nonaka and Takeuchi, 1995), strategic management based on the development of core competencies (Prahalad and Hamel, 1990), etc. are all based on models where the implicit assumption of continuity is present.

Based on such considerations, the following proposition can be established regarding the nature of the technological innovation process:

P1a. The technological innovation process is essentially continuous in nature.

3.2. Path dependency

The assumption that the innovation process is path dependent occupies a central place in the evolutionary approach and reflects the fact that the evolution of a technology depends fundamentally on the path it followed in the past (path dependency). This idea can be outlined in three phases (Arthur, 1989):

(1) at any given moment, the choice between two different alternative technologies that serve the same function is influenced by previously made choices;
(2) minor historical events that took place at the beginning of the process and the content of the initial choices play an essential role in its future evolution; and
(3) previous choices determine not just the next choice, but the possibility that each alternative will be chosen.

The technological decisions made now present will condition the subsequent learning process, determining the future path of the innovation process (David, 1975, p. 4). In the context of the competition between two technologies that appear at the same time, the content of the initial decisions has a great deal of importance. Thus, different insignificant events, such as the unexpected success of the development of the first prototype, the order in which the technologies reach the market, the whims of early adopters, political circumstances, etc. can cause a given technology to achieve a large enough base to become dominant (Arthur, 1989). The sequence in which such events occur, no matter how insignificant they may be, will affect the dissemination of each alternative technology and will condition its future development.

This assumption is implicit in different concepts habitually used in innovation studies. It is usual to reflect the cumulative nature of the innovation process by representing the evolution of technologies through a "technological trajectory" (Dosi, 1982) or "innovation avenue" (Sahal, 1985). These technological trajectories/avenues run within the context of certain "technological paradigms" (Dosi, 1982) or "technological regimes" (Nelson and Winter, 1982). Such technological paradigms/regimes in turn establish "technological guideposts" (Sahal, 1985) or define "dominant designs" (Abernathy and Utterback, 1978) that determine the future development of technologies. In other words, technological paradigms, technological regimes, technological guideposts and dominant designs are similar concepts that reflect the historical factors that determine the future evolution of the innovation process along technological trajectories or avenues, hence the following proposition:

P1b. The technological innovation process is path-dependent.

3.3. Irreversibility

The development of a technology, in the context of a given technological trajectory, generates new knowledge through a series of feedback mechanisms that contribute to improving its yield. These mechanisms reinforce this dominant technology to the detriment of other alternative technologies with which it competes. There are various types of positive feedback that make the technological innovation process irreversible (Arthur *et al.*, 1987):

(1) *Learning by doing* (Arrow, 1962a). This arises spontaneously from the performance of repetitive tasks in production activities. Learning by doing has different manifestations, some of which have been thoroughly studied, such as the learning effect and the experience effect (Abernathy and Wayne, 1974).

(2) *Learning by using* (Rosenberg, 1982). When users come into contact with a new technology other forms of use arise that were not initially foreseen and design improvements based on the experience of clients. The potentiality of this mode of learning is especially manifested in high-technology sectors.

(3) *Network externalities*. As a technology is disseminated, externalities usually arise, called network effects, which improve its performance. This phenomenon can take two forms (David, 1987):
   - direct effects: the mere increase in the number of users of a technology (e.g. e-mail) increases its usefulness for everyone; and
   - indirect effects: due to improvements in the supply of supplementary services (e.g. DVD).

(4) *Economies of scale*. The diffusion and mass use of a technology allows the mass production of the material elements that form part of such new technology (machines, facilities, components) and thus diminish their unit cost of production.

(5) *Complementary technologies*. The diffusion of a technology induces the development of new techniques of a supplementary nature that ensure the proper functioning and/or improve the performance of the technology in question (Teece, 1987).

(6) *The flow of information available about the new technology*. As a technology is disseminated, a large amount of information is generated, which contributes to the improvement of the knowledge of the technology. The spread of information about a given technological alternative influences the behavior of potential users and can eventually contribute to improve its performance (Hall, 1994, p. 272).

In short, the combined action of these six feedback mechanisms contributes to making the innovation process irreversible. The more a technology is disseminated, the greater the possibility that it will continue to spread in the future. There are increasing advantages for adoption due to learning, network effects, economies of scale and supplementary technologies. Abandoning a technological trajectory means forsaking these advantages. In fact, the evolution of technologies along certain trajectories prevents the old rejected alternative technologies from competing even is their relative pricing structures are significantly different (Teece, 1996). Therefore, the following proposition can be suggested:

P1c. The technological innovation process is partially irreversible.

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3.4. Uncertainty

The most significant characteristic of the innovation process is the high level of uncertainty that surrounds the performance of all innovative activities. The origins of this uncertainty are very diverse and their effects appear throughout the innovation process. Three modes of uncertainty are identified in the literature:

(1) *The technical uncertainty that is inextricably linked to R&D activities*. This reflects the lack of a priori knowledge regarding what the solution to the technical problem will be or whether it will even be found within the foreseen time frames and costs: What is the best technical solution? Is it feasible? Will it work?

   The importance traditionally given to this aspect has overshadowed the effect of other, more subtle sources of uncertainty that crop up after the completion of the "technical" phase of the innovation process, when the technology comes into contact with the market. At first blush, it could be thought that the uncertainty decreases radically once the new technology has been brought to market. However, this is not the case. After the company has successfully concluded its R&D project and begins to commercialise a new technology, new uncertainties start to appear, originating from lack of knowledge regarding (Rosenberg, 1996): the possible uses of the technology and the evolution of its technical performance in the future.

(2) *Uncertainty about possible uses of the technology.* When a new technology appears its possible future uses and utility are not apparent. There are hundreds of historical examples that show the inability, at least in retrospect, of the innovators to foresee the uses that their new technologies will have. For example, in 1949 IBM's legendary president Thomas Watson thought that the potential use of the computer was limited to number crunching in a few scientific research or data processing contexts, rejecting the idea that it could have a potentially wide market.

(3) *Uncertainty about the future evolution of the technology's performance*. Another source of uncertainty is related to the inability to anticipate future improvements of the technology and its economic consequences (Rosenberg, 1996). Many new technologies, when they appear, have characteristics that do not allow their properties to be immediately appreciated. In general, when they are born they are still imperfect and are in a very primitive form. Their potential uses arise as a result of a long process of incremental improvements that widen the scope of their practical application. A case in point is the extraordinary evolution of the performance of computers since their appearance in the 1940s.

These three modes of uncertainty justify the following proposition:

P1d. The technological innovation process is affected by different types of uncertainty.

It should be pointed out that efforts to minimize the effects of uncertainty by establishing technological predictions are not very useful because, due to the characteristic of irreversibility, there is no guarantee that the most efficient alternative technology will prevail. Numerous studies (David, 1985; Arthur *et al.*, 1987) have found that the final outcome of the dissemination process, in which various technological alternatives compete, cannot be predicted at the start of the process. It is impossible to determine which technological alternative will prevail. In this context, technological prediction becomes a game of chance.

4. Characteristics of technology

Traditionally, due to the neo-classical influence, technological innovation has been considered as a process that generates information from information. Thus technology has been analyzed as an information-intensive good, which possessed the attributes of public goods. Arrow (1962b), in a seminal work, which had a notable influence on subsequent research, pointed out that these particular characteristics of technology caused three types of problems:

(1) It is difficult to establish property rights on a technology since the cost of reproducing it – insofar as it consists of information – is practically nil.
(2) Technology is subject to indivisibilities and there is no rivalry in its consumption, due to the fact that the act of consuming information is not destructive.
(3) The marketing technology poses problems of adverse selection since the fact that technology has the characteristics of information favors opportunistic behavior by agents.

These three observations have contributed to reinforce the idea that the market failures caused by the production and marketing of technology are due exclusively to the fact that it is "information". However, recent studies have substantially modified how the innovation process is viewed, by considering that technology is not free-use good like information, but rather that it has a strong learning and accumulated knowledge component. The technological innovation process not only produces "information" but also generates "knowledge" which reverts exclusively to the innovator (Geroski, 1995, p. 93). Thus, various aspects gain special relevance insofar as knowledge can be:

(1) codified;
(2) transmitted;
(3) assimilated; and
(4) appropriated.

These four characteristics are discussed below.

4.1. Tacit dimension

The possibility of being codified is undoubtedly the most significant characteristic of knowledge. The codification of knowledge refers to the possibility of a given piece of knowledge to be reduced to information through drawings, formulas, numbers or words. Based on the degree of codification, two categories of knowledge have been defined: explicit[2] and tacit[3].

Explicit knowledge is fully articulated, codified in a precise manner and perfectly decipherable. The main ingredient of explicit knowledge is information and therefore its transmission and accumulation does not entail any great difficulty. The examples of this type of knowledge are extremely varied; however, they can be grouped in to the following four categories (Badaracco, 1991, pp. 17-19):

(1) knowledge contained in documents, blueprints or databases;
(2) knowledge contained in machinery and production equipment;
(3) knowledge contained in certain raw materials, such as chemical and pharmaceutical products, special metal alloys, new materials, etc.; and
(4) part of the knowledge contained in the minds of individuals and that can be transmitted easily.

The tacit dimension of knowledge is that which cannot be reduced to information and therefore, cannot be codified. Most technological knowledge has a large tacit component and thus cannot be completely transmitted not even by the person who possesses it. All of us know more than we are capable of explaining (Polanyi, 1967, p. 4). The body of tacit knowledge includes all that which one knows how to do, but cannot describe how. This knowledge comes from personal actions and from experience, which is why it is difficult to share with others.

The line that divides tacit and explicit knowledge is difficult to establish because both types of knowledge are integrated in organizational routines that manage the innovation process (Nelson and Winter, 1982; Spender, 1996). It has already been pointed out that companies create new knowledge through different modes of learning (by studying, by using, by doing, and by failing). As the input for this process a wide variety of knowledge is use, with different degrees of codification: explicit (perfectly codified in written rules and bureaucratic procedures) and tacit (which have not been formalized but form part of the company's culture or know-how). All companies, even high-tech ones, that fundamentally feed off knowledge that is very close to science, and therefore, easily codified, process some kind of tacit knowledge (Dosi, 1988).

In general terms, the innovation process seeks to resolve different technological problems that are usually neither well structured, nor perfectly defined. For example if one wants to improve the design of a machine tool in order to reduce its failure rate, one has to discover the physical causes of failure, which can be very diverse. The initially available explicit knowledge does not in itself provide a solution to the problem automatically. Something more is needed. What are needed are other specific capabilities of a tacit nature, such as accumulated experience, intuition or creativity. Therefore, the following proposition can be formulated:

P2a. All technology is made up of two types of knowledge, codified (information) and tacit.

4.2. Transmission

Technological resource markets have imperfections that make it difficult to identify, acquire and assimilate technologies (Teece, 1984). Usually, companies have a hard time identifying the technologies that will provide the most competitive impact and acquiring them in the factor market. This effect, called "causal ambiguity" (Reed and DeFillippi, 1990), hinders the transfer and dissemination of technological knowledge, insofar as it increases the risk that the outcome of the imitation may not be the expected one. These difficulties constitute real barriers that hinder the transmission of technologies, and depend on multiple factors.

First, the possibility that a given piece of technological knowledge can be freely transferred (or imitated) and the speed of its dissemination will depend on certain characteristics of the knowledge itself (Rogers, 2003; Winter, 1987; Zander and Kogut, 1995; Grant, 1996) such as the following:

- degree of codification;
- degree to which it can be taught;
- degree of complexity;

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- degree of dependence on other knowledge; and
- degree to which it can be observed.

On the other hand, even if the company is able to identify the relevant technology, it would still have to deal with the problem consisting of the fact that technological knowledge does not have perfect mobility. The transfer of technological knowledge, even if it is perfectly codified, is associated with high transaction costs. Geographic immobility, opportunistic behaviors induced by imperfect information and the idiosyncratic nature of most technological resources are factors that contribute to hinder their transfer (Grant, 2002, p. 179). Because of this, the truth is that technological resources of a strategic nature cannot be bought or lose part of their productivity on being transferred to other companies:

P2b. The transmission of technologies is imperfect due to multiple factors such as certain characteristics of knowledge, the existence of causal ambiguity or transaction costs.

4.3. Assimilation

As pointed out earlier, technological advances, within each technological trajectory, occur in a continuous manner along a path within the boundaries of each technological paradigm. Innovations come about based on the development and improvement of existing technologies, and advances in technological knowledge occur in a sequential manner, where one phase needs to be mastered before moving on to the next one (Teece, 1996). As a result, companies innovate – they create new products and processes or improve existing ones – obtaining the maximum advantage from their technological potential. First, they try to obtain the knowledge needed to do this based on previously accumulated knowledge (Teece, 1996). This is why the technological innovation process at the company level will have a clearly cumulative nature. Furthermore, it is reasonable to assume that what a company can achieve technologically in the future will depend on what it had been capable of doing in the past (Dosi, 1988).

The cumulative nature of technological knowledge can also be seen in the case of companies that decide – and are able to – acquire technology on the technological factor market. In general, companies that lack prior knowledge of a supplementary nature will not have the absorption capacity needed to assimilate quickly new technologies coming from the outside (Cohen and Levinthal, 1990). The development of the supplementary resources needed to assimilate a technology and the learning process itself is time-consuming. New technologies cannot be instantly adopted, but rather are gradually assimilated. Based on this, the following proposition can be formulated:

P2c. The assimilation of a new technology is not instant and depends on the level of technological knowledge previously accumulated by the company, that is to say, its absorption capacity.

4.4. Appropriation

The economic literature points out that the benefits generated by innovative activities are not perfectly susceptible to appropriation. Companies encounter difficulties in establishing intellectual property rights over part of its technological knowledge (Geroski, 1995, p. 92). Every technology has two components: a private one, which only the innovating company benefits from, and a public one, which is difficult to appropriate, and which other agents take advantage of (Dosi, 1988). The conditions of appropriability of a technology determine the percentage of each of these components.

Certain conditions of appropriability are exogenous, insofar as they depend on factors that the company cannot control such as the characteristics of the knowledge, the institutional framework, the legal system or the structure of the industry. However, other conditions are clearly endogenous, since they depend on the strategies of the company. Companies have different mechanisms for appropriating the results of their innovative activities (Levin *et al.*, 1987; Teece, 1987; Geroski, 1995) such as:

- legal protection measures;
- secrecy;
- exploitation of a technological leadership position;
- taking advantage of lag times; and
- using complementary assets.

These mechanisms are briefly discussed below.

Legal protection measures (patents, trademarks, copyright) make it possible to prevent copying by imitators, and also ensure revenues from royalties. However, the effectiveness of these legal measures has been seriously questioned. Levin *et al.* (1987) pointed out different causes that explain why in most industries patents are not used as protection mechanism against imitators. In many industries, imitators – without running afoul of the law – can copy around the patented technology since it is usually difficult to prove that the imitator has copied anything (e.g. complex electronic systems). Some innovations are very difficult to patent since it is very expensive to prove their novelty (e.g. complex and mature

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technologies). In certain technological trajectories, advances come at such a fast pace that it does not make any sense to patent them (e.g. microelectronics). In other cases innovations are not legally protected because the complexity of the technology makes it nearly as costly, in terms of time and money, as developing the technology (e.g. electronics, aerospace, industrial machinery).

This is why it was pointed out that other protection mechanism could be more effective. There are situations in which the information included in the patent limits its effectiveness and the protection mechanism used is usually industrial secrecy (e.g. Coca Cola, petrochemical processes). In general, actions aimed at exploiting a position of technological leadership through heavy investment in marketing and customer service have demonstrated their effectiveness in certain industries such the semiconductor industry. On the other hand, the time lag or temporal advantage of the innovator could be an effective protection mechanism against imitators. If the innovator continues to accumulate knowledge and to innovate continuously, it will manage to keep a technological lead over potential imitators. Another factor that could affect appropriability is related to the fact that, in order to exploit a technology, it is necessary to have certain supplementary resources of a co-specialized nature (Teece, 1987). These resources affect the conditions of appropriation insofar as the imitator also needs to gain access to such resources. In these cases the innovator can appropriate the benefits by establishing agreements and controlling the suppliers:

P2d. The profits generated by a technology are not perfectly appropriable, but rather depend of the effectiveness of the protection mechanisms used by the firms.

5. Conclusions

This paper has analyzed two key elements for the study of corporate technological innovation management: the concept of technological innovation and the concept of technology.

The concept of technological innovation is used to describe the learning process through which the company generates a flow of new technological knowledge, competencies and capabilities based on inputs that are also knowledge-intensive. This is a dynamic process that has the following characteristics:

(1) The innovation process is of an essentially continuous nature, insofar as most innovations originate from small incremental improvements.

(2) The innovation process is path dependent. At any given moment, decisions regarding the adoption of a certain technology are conditioned by a whole sequence of decisions made in the past. Minor events that occurred at the beginning of the process have a great deal of importance and condition its future evolution.

(3) The innovation process is partially irreversible and this strong resistance to the abandonment of a technological trajectory. This is due to a series of positive feedback mechanisms such as:
- learning by doing;
- learning by using;
- network effects;
- complementary technologies;
- economies of scale; and
- the dissemination of information about the new technology.

(4) The technological innovation process is affected by different types of uncertainty such as:
- technical uncertainty;
- uncertainty about the possible uses of the technology; and
- uncertainty regarding the evolution of its performance.

The concept of technology reflects the stock of knowledge, competencies and capacities that a company has at a given moment in time. Technology is the output and the main input of the innovation process and has the following characteristics:

- All technology is made up of two kinds of knowledge: codified (information) and tacit.
- The transmission of technology is imperfect due to certain characteristics of knowledge, causal ambiguity, and the existence of transaction costs.
- The assimilation of a new technology is not instantaneous and will depend on the level of technological knowledge previously accumulated by the company, that is to say, its absorption capacity.
- The benefits generated by a technology are not perfectly appropriable but rather depend on the effectiveness of the protection mechanisms used by the company.

These propositions regarding the characteristics of the technological innovation process and technology are consistent with the assumptions established by evolutionary economics and the resource-based approach. They present a dynamic vision that better reflects the historical and temporal nature of the technological innovation process. Based on this foundation, models can be built to analyze the technological innovation process in firms and improve the theoretical basis of technological strategy design.

Notes

1 Note that it is common to use the term innovation to signify both the result (product) of the technological innovation process, and the entire technological process as a whole or just one of the phases in the invention-innovation-diffusion sequence.
2 Different terms have been used in the literature to refer to explicit knowledge: "articulable" (Winter, 1987, p. 170; Nelson and Winter, 1982, p. 77), "codificability" (Zander and Kogut, 1995, p. 79), "migratory" (Badaracco, 1991, p. 16), "information" (Kogut and Zander, 1992, p. 386), "specific" (Dosi, 1988, p. 1131) and, of course, "explicit" (Grant, 1996, p. 111; Nonaka and Takeuchi, 1995, p. 9; Polanyi, 1962; Spender, 1996, p. 52).
3 The terms "know-how" (Kogut and Zander, 1992, p. 386) and "embedded knowledge" (Badaracco, 1991, p. 53) have been used to refer to tacit information.

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