UNIVERSITÀ POLITECNICA DELLE MARCHE
FACOLTÀ DI ECONOMIA “GIORGIO FUÀ”

Dottorato di Ricerca in Management and Law
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TECHNOLOGY FORECASTING, INNOVATION AND FIRM PERFORMANCE IN NEW MATERIALS INDUSTRIES

Tutor:
Chiar.mo Prof. Marco Cucculelli

Tesi di dottorato di:
Dott. Raoul Cafrullo

Coordinatore del Dottorato di Ricerca:
Chiar.mo Prof. Enrico Cori

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Acknowledgements

Innovation is an intriguing process, a force that is able to exercise aesthetic and pragmatic appeal that triggers the creative spirit and opens the mind to opportunities unknown until a new idea become reality, boosting economic growth and making it a protagonist of progress in key areas for human development.

Innovation offers companies, which represent the primary engine of economic progress, extraordinary opportunities, and poses serious challenges. Improvements, in addition to being a powerful means of competitive differentiation, enable firms to approach new markets and reach higher profit and is also a competitive race that requires rapidity, skill and precision. Being innovative is not enough; to be successful companies have to be able to innovate better than the competitors. In many economic fields, technological innovation has become the determining factor in competitive success: for most companies, innovation is now a key strategic imperative to maintain and acquire leadership positions in the market as well as recovering competitive disadvantages. In this work, the process of innovation is considered as a strategic process.

In the first part we analyze how creativity converts into innovative products, made by the individual elements of the innovation system, such as companies, as well as through links between the actors involved, such as business and customer relations.

Then are described some commonly accepted criteria used to distinguish the technological innovation forms and later the S-curve patterns that occur very often when observing the trend of technological performance and the process of disseminating technology in the market. Afterword the advantages and disadvantages of the first mover are described and, at a later stage, the factors influencing the time of entry and its reflections on the company's strategy are more closely observed. Work continues with the presentation of key evaluation and selection methods for innovation projects, ranging from strictly quantitative to qualitative and mixed methods approaches.

Recent advances in technologies rely on sophisticated materials: all of them used devices, products, and systems that consist of materials. With the rapid advances in computer technology, design engineering has become quite sophisticated. Thus, it has been shown that depending on the selection criterion there are different types of materials. Based on chemical make up and atomic structure, solid materials have been grouped into three basic categories: metals, ceramics and polymers; between the engineering materials there are three other important groups: composites, semiconductors and biomaterials; then, in high-technology sectors, has been developed the advanced materials and recently, a group of new and state-of-the-art materials called as "smart materials" is under development.

In the second part is being proposed a method for forecasting technology success based on patent data. Four criteria, technology life cycle, diffusion speed, patent power, and expansion potential are considered for technology forecasting. Patent power and expansion potential are considered as technology scope indicators. At the end of the estimating process a data fusion algorithm is applied to combine the results obtained from different criteria. The proposed forecasting approach usefulness and potential has been demonstrated using 21.454 patents related to the following types of material: Advanced Materials, Alloys, Biomaterials, Ceramics, Composites, Gases, Metals, Nanomaterials, Polymers, Semiconductors.

In the third chapter the proposed study aims to assess how far and under which conditions granted patents provide economic advantage over companies. Based on a set of 21.545 patents held by European companies, the impact on Return on Assets index (Roa) was estimated. This part investigates how the granted patents, firm age and technology domains of new materials firms affect company performance in the time windows 2007-2015.

Finally, in the last chapter, the research examines the role of entering into new technology sectors and how the effects of the ramifications on innovative activity vary according to the number of sectors. Then, in a second step, the firm performance effect is estimated on the model. To assess whether the technological expansion is affected by the number of sectors, a dataset of 9,917 companies, operating in the advanced materials sector, over the period 1995 to 2016 is examined. Investigating companies patent portfolios and their compositions, it was possible to establish whether the firm is operating in one or more technological field. After explaining the results, some possible policy implications are described.

CHAPTER ONE

THE INNOVATION TECHNOLOGY

1.1 The importance of innovation technology

In many industries technological innovation is now the most important driver of competitive success. Firms in a wide range of industries rely on products developed within the past five years for almost one-third (or more) of their sales and profits[1]. The increasing importance of innovation is due in part to the globalization of markets: foreign competition has put pressure on firms to continuously innovate in order to produce differentiated products and services. Introducing new products helps companies protect their margins, while investing in process innovation helps firms lower their costs. Advances in information technology also have played a role in speeding the pace of innovation. Computer-aided design and computer-aided manufacturing have made it easier and faster for firms to design and produce new products, while flexible manufacturing technologies have made shorter production runs economical and have reduced the importance of production economies of scale[2]. These technologies help firms develop and produce more product variants that closely meet the needs of narrowly defined customer groups, thus achieving differentiation from

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[1] Barczak G., Griffin A., Kahn K. B., "Trends and drivers of success in npd practices: results of the 2003 pdma best practices study" Journal of Product Innovation Management 26, (2009).

[2] Womack J. P., Jones D. T., Roos D., "The machine that changed the world" Rawson Associates, (1990).

competitors. While producing multiple product variations used to be expensive and time consuming, flexible manufacturing technologies now enable firms to seamlessly transition from producing one product model to the next, adjusting production schedules with real-time information on demand. Firms further reduce production costs by using common components for many of the models.

Many firms such as Toyota, Samsung, and Sony adopt these new technologies and increase their pace of innovation, they raise the bar for competitors, triggering an industrywide shift to shortened development cycles and more rapid new product introductions. The net results are greater market segmentation and rapid product obsolescence[3]. Product life cycles have become as short as 4 to 12 months for software, 12 to 24 months for computer hardware and consumer electronics, and 18 to 36 months for large home appliances[4]. This spurs firms to focus increasingly on innovation as a strategic imperative: a firm that does not innovate quickly gets its margins diminishing as its products become obsolete[5].

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[3] Qualls W., Olshavsky R. W., Michaels R. E. "Shortening of the plc—an empirical test" Journal of Marketing 45, (1981).

[4] Schilling M. A., Vasco C. E. "Product and process technological change and the adoption of modular organizational forms" Winning Strategies in a Deconstructing World, John Wiley & Sons, (2000).

[5] Schilling M. A. "Strategic management of technological innovation", McGraw-Hill Education, 4th edition, (2012)

1.2 The impact of technology innovation on society

If pushing for innovation has raised the competitive bar for industries, arguably making success just that much more complicated for organizations, its net effect on society is more clearly positive. Innovation enables a wider range of goods and services to be delivered to people worldwide. It has made the production of food and other necessities more efficient, yielded medical treatments that improve health conditions, and enabled people to travel to and communicate with almost every part of the world. In a series of economic growth studies conducted by the National Bureau of Economic Research, economists showed that the historic rate of economic growth in GDP could not be accounted for entirely by growth in labor and capital inputs. Economist Robert Merton Solow argued that this unaccounted-for residual growth represented technological change: Technological innovation increased the amount of output achievable from a given quantity of labor and capital. This explanation was not immediately accepted; many researchers attempted to explain the residual away in terms of measurement error, inaccurate price deflation, or labor improvement. But in each case the additional variables were unable to eliminate this residual growth component. A consensus gradually emerged that the residual did in fact capture technological change. Solow received a Nobel Prize for his work in 1981, and the residual became known as the Solow Residual[6]. While GDP has its shortcomings as a measure of standard of living, it does relate very directly to the amount of goods consumers can purchase. Thus, to the extent that goods improve quality of life, we can ascribe some beneficial impact of technological innovation.

Sometimes technological innovation results in negative externalities. Production technologies may create pollution that is harmful to the surrounding communities; agricultural and fishing technologies can result in erosion, elimination of natural habitats, and depletion of ocean stocks; medical technologies can result in unanticipated consequences such as antibiotic resistant strains of bacteria or moral dilemmas regarding the use of genetic modification. However, technology is, in its purest essence, knowledge-knowledge to solve our problems and pursue our goals[7]. Technological innovation is thus the creation of new knowledge that is applied to practical problems. Sometimes this knowledge is applied to problems hastily, without full consideration of the consequences and alternatives, but overall it will probably serve us better to have more knowledge than less.

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[6] Crafts N., "The first industrial revolution: a guided tour for growth economists," The American Economic Review 86, (1996).

[7] Simon H. A., "Technology and environment," Management Science 19, (1973)

1.3 Sources of innovation

Innovation can arise from many different sources. One primary engine of innovation is firms. Firms are well suited to innovation activities because they typically have greater resources than individuals and a management system to marshal those resources toward a collective purpose. Firms also face strong incentives to develop differentiating new products and services, which may give them an advantage over non-profit or government-funded entities.

An even more important source of innovation, however, does not arise from any one of these sources, but rather the linkages between them. Networks of innovators that leverage knowledge and other resources from multiple sources are one of the most powerful agents of technological advance. We can thus think of sources of innovation as composing a complex system wherein any particular innovation may emerge primarily from one or more components of the system or the linkages between them.

1.3.1 The role of creativity

Innovation begins with the generation of new ideas. The ability to generate new and useful ideas is termed creativity. Creativity is defined as the ability to produce work that is useful and novel. Novel work must be different from work that has been previously produced and surprising in that it is not simple the next logical step in a series of known solutions[8]. The degree to which a product is novel is a function both of how different it is from prior work (e.g., a minor deviation versus a major leap) and of the audience's prior experiences[9]. A product could be novel to the person who made it, but known to most everyone else. In this case, we would call it reinvention. A product could be novel to its immediate audience, yet be well known somewhere else in the world. The most creative works are novel at the individual producer level, the local audience level, and the broader societal level[10]. An **individual's creative** ability is a function of his or her intellectual abilities, knowledge, style of thinking, personality, motivation, and environment[11]. The most important intellectual abilities for creative thinking include the ability to look at problems in unconventional ways, the ability to analyze which ideas are worth pursuing and which are not, and the ability to articulate those ideas to

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[8] Lubart T. I. "Creativity" Thinking and Problem Solving, R. J. Sternberg, (1994)

[9] Boden M. "The creative mind: myths and mechanisms" Basic Books, (1992).

[10] Schilling M. A. "Strategic management of technological innovation" McGraw-Hill Education, 4th edition, (2012)

[11] Sternberg R. J., Lubart T. I. "The concept of creativity: prospects and paradigms" Cambridge University Press, (1999)

others and convince others that the ideas are worthwhile. The impact of knowledge on creativity is somewhat double-edged. If an individual has too little knowledge of a field, he or she is unlikely to understand it well enough to contribute meaningfully to it. On the other hand, if an individual knows a field too well, that person can become trapped in the existing logic and paradigms, preventing him or her from coming up with solutions that require an alternative perspective. Thus, an individual with only a moderate degree of knowledge of a field might be able to produce more creative solutions than an individual with extensive knowledge of the field[12]. The personality traits deemed most important for creativity include self-efficacy, tolerance for ambiguity, and a willingness to overcome obstacles and take reasonable risks[13]. Intrinsic motivation has also been shown to be very important for creativity[14]. That is, individuals are more likely to be creative if they work on things they are genuinely interested in and enjoy. Finally, to fully unleash an individual's creative potential often requires an environment that provides support and rewards for creative ideas.

The **creativity of the organization** is a function of the individuals within the organization and a variety of social processes and contextual factors that shape the

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[12] Frensch P. A., Sternberg R. J. "Expertise and intelligent thinking: when is it worse to know better?" in advances in the psychology of human intelligence 5, (1989)

[13] Lubart T. I. "Product-centered self-evaluation and the creative process" unpublished doctoral dissertation, Yale University Press, (1994)

[14] Amabile T. M. "Creativity in context" Boulder, Westview press, (1996)

way those individuals interact and behave[15]. An organization's overall creativity level is thus not a simple aggregate of the creativity of the individuals it employs. The organization's structure, routines, and incentives could thwart individual creativity or amplify it.

The most familiar method of a company tapping the creativity of its individual employees is the suggestion box. In 1895, John Patterson, founder of National Cash Register (NCR), created the first sanctioned suggestion box program to tap the ideas of the hourly worker[16].The program was considered revolutionary in its time. The originators of adopted ideas were awarded $1. In 1904, employees submitted 7,000 ideas, of which one-third were adopted. Other firms have created more elaborate systems that not only capture employee ideas, but incorporate mechanisms for selecting and implementing those ideas. Idea collection systems, such as suggestion boxes, are relatively easy and inexpensive to implement, but are only a first step in unleashing employee creativity. Today many companies go to much greater lengths to tap the creative potential embedded in employees, including investing in creativity training programs. Such programs encourage managers to develop verbal and nonverbal cues that signal employees that their thinking and autonomy are respected. These cues shape the culture of the firm and

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[15] Woodman R. W., Sawyer J. E., Griffin R. W. "Toward a theory of organizational creativity" Academy of Management Review 18, (1993)

[16] Gorski C., Heinekamp E. "Capturing employee ideas for new products" John Wiley & Sons, (2002)

are often more effective than monetary rewards and, sometimes, monetary rewards undermine creativity by encouraging employees to focus on extrinsic rather than intrinsic motivation[17]. The programs also often incorporate exercises that encourage employees to use creative mechanisms such as developing alternative scenarios, using analogies to compare the problem with another problem that shares similar features or structure, and restating the problem in a new way[18].

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[17] Woodman R. W., Sawyer J. E., Griffin R. W. "Toward a theory of organizational creativity" Academy of Management Review 18, (1993)

[18] Schilling M. A. "Strategic management of technological innovation" McGraw-Hill Education, 4th edition, (2012)

1.3.2 Actors of innovation

Innovation can arise from many different sources. It can originate with individuals, as in the familiar image of the lone inventor or users who design solutions for their own needs. Innovation can also come from the research efforts of universities, government laboratories and incubators, or private non-profit organizations. One primary engine of innovation is firms. Firms are well suited to innovation activities because they typically have greater resources than individuals and a management system to marshal those resources toward a collective purpose. Firms also face strong incentives to develop differentiating new products and services, which may give them an advantage over nonprofit or government funded entities.

An even more important source of innovation, however, does not arise from any one of these sources, but rather the linkages between them. Networks of innovators that leverage knowledge and other resources from multiple sources are one of the most powerful agents of technological advance[19]. We can thus think of sources of innovation as composing a complex system where in any particular innovation may emerge primarily from one or more components of the system or the linkages between them.

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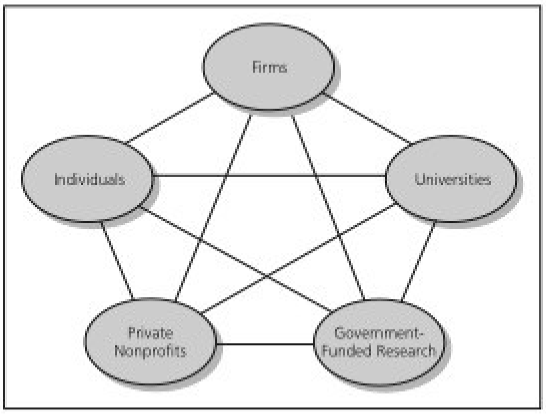
[19] Doerr L. S., Smith J. O., Koput K. W., Powell W. W. "Networks and knowledge production: collaboration and patenting in biotechnology" Corporate Social Capital, (1999)

Fig. 1.1 S-curve of technology life cycle



Below are summarized the main sources of innovation[20]:

a) The **Inventor**: The familiar image of the inventor as an eccentric and doggedly persistent scientist may have some basis in cognitive psychology. Analysis of personality traits of inventors suggests these individuals are likely to be interested in theoretical and abstract thinking, and have an unusual enthusiasm for problem solving. Their tendency toward introversion may cause them to be better at manipulating concepts than at interacting socially[21]. Such individuals may spend a lifetime developing numerous creative new devices or processes, though they may patent or commercialize few. The qualities that make people inventive do not necessarily make them

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[20] Schilling M. A. “Strategic management of technological innovation” McGraw-Hill Education, 4th edition, (2012)

[21] Church A. H., Waclawski J. “The relationship between individual personality orientation and executive leadership behavior” Journal of Occupational and Organizational Psychology 71, (1998)

entrepreneurial; many inventors do not actively seek to patent or commercialize their work. Many of the most well-known inventors (e.g., Alexander Graham Bell, Thomas Alva Edison, Albert Einstein, and Benjamin Franklin), however, had both inventive and entrepreneurial traits.

b) Innovation **by Users**: Innovation often originates with those who create solutions for their own needs. Users often have both a deep understanding of their unmet needs and the incentive to find ways to fulfill them[22]. While manufacturers typically create new product innovations in order to profit from the sale of the innovation to customers, user innovators often have no initial intention to profit from the sale of their innovation—they create the innovation for their own use[23]. Users may alter the features of existing products, approach existing manufacturers with product design suggestions, or develop new products themselves. User innovations can also blossom into new industries.

c) **Research and Development by firms**: Though the terms research and development are often lumped together, they actually represent different kinds of investment in innovation related activities. Research can refer to both basic research and applied research. *Basic research* s effort directed at increasing

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[22] Von Hippel E. "Innovation by user communities: learning from open-source software," Sloan Management Review 42, (2001)

[23] Shah S. K., "Motivation, governance, and the viability of hybrid forms in open source software development," Management Science 52, (2006)

understanding of a topic or field without a specific immediate commercial application in mind. This research advances scientific knowledge, which may turn out to have long-run commercial implications. *Applied research* is directed at increasing understanding of a topic to meet a specific need. In industry, this research typically has specific commercial objectives. *Development* refers to activities that apply knowledge to produce useful devices, materials, or processes. Thus, the term research and development refers to a range of activities that extend from early exploration of a domain to specific commercial implementations.

d) **Linkages to an external network of firms**: Firms often form alliances with customers, suppliers, and even competitors to jointly work on an innovation project or to exchange information and other resources in pursuit of innovation. Collaboration might occur in the form of alliances, participation in research consortia, licensing arrangements, contract research and development, joint ventures, and other arrangements. Collaborators can pool resources such as knowledge and capital, and they can share the risk of a new product development project. Critics have often charged that firms are using external sources of technological innovation rather than investing in original research. But empirical evidence suggests that external sources of information are more likely to be complements to rather than substitutes for in-house research and development. Researches indicate that firms who had their own research and development were also the heaviest users of external collaboration networks. Presumably doing in-house R&D helps to build the firm's absorptive capacity, enabling it to better assimilate and utilize information obtained externally[24]. Absorptive capacity refers to the firm's ability to understand and use new information.

e) **Universities, government laboratories, and incubators**: Many universities encourage their faculty to engage in research that may lead to useful innovations. Typically the intellectual property policies of a university embrace both patentable and unpatentable innovations, and the university retains sole discretion over the rights to commercialize the innovation. If an invention is successfully commercialized, the university typically shares the income with the individual inventors[25]. Governments of many countries actively invest in research through their own laboratories, the formation of science parks and incubators, and grants for other public or private research entities. These parks create fertile hotbeds for new start-ups and a focal point for the collaboration activities of established firms. Their proximity to university laboratories and other research centers ensures ready access to

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[24] Cohen W. M., Levinthal D. A. "Absorptive capacity: a new perspective on learning and innovation," Administrative Science Quarterly, (1990)

[25] Silverman A. "Understanding university patent policies" Journal of Management 55, (2003)

scientific expertise. Such centers also help university researchers implement their scientific discoveries in commercial applications[26].

f) **Private Nonprofit Organizations**: Private non-profit organizations, such as private research institutes, non-profit hospitals, private foundations, professional or technical societies, academic and industrial consortia, and trade associations, also contribute to innovation activity in a variety of complex ways. Many non-profit organizations perform their own research and development activities, some fund the research and development activities of other organizations but do not do it themselves, and some non-profit organizations do both in-house research and development and fund the development efforts of others.

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[26] Colombo M., Delmastro M. “How effective are technology incubators? evidence from Italy” Research Policy 31, (2001)

1.3.3 Collaborative networks

There is a growing recognition of the importance of collaborative research and development networks for successful innovation[27]. Such collaborations include joint ventures, licensing and second sourcing agreements, research associations, government-sponsored joint research programs, value added networks for technical and scientific interchange, and informal networks[28]. Collaborative research is especially important in high-technology sectors, where it is unlikely that a single individual or organization will possess all of the resources and capabilities necessary to develop and implement a significant innovation[29].

As firms forge collaborative relationships, they weave a network of paths between them that can act as conduits for information and other resources. By providing member firms access to a wider range of information than individual firms possess, interfirm networks can enable firms to achieve much more than they could achieve individually[30]. Thus, interfirm networks are an important engine of innovation. Furthermore, the structure of the network is likely to influence the flow of information and other resources through the network.

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[27] Ahuja G., Lampert C. M. “Entrepreneurship in the large corporation: a longitudinal study of how established firms create breakthrough inventions” Strategic Management Journal 22, (2001)

[28] Freeman C. “Networks of innovators: a synthesis of research issues” Research Policy 20, (1991)

[29] Hagedoorn J. “Inter-firm R&D partnerships: an overview of major trends and patterns since 1960” Research Policy 31, (2002)

[30] Liebeskind J.P., Oliver A.L., Zucker L., Brewer M. “Social networks, learning, and flexibility: sourcing scientific knowledge in new biotechnology firms” Organization Science 4, (1996)

Sometimes geographical proximity appears to play a role in the formation and innovative activity of collaborative networks. City and state governments, for example, might like to know how to foster the creation of a technology cluster in their region in order to increase employment, tax revenues, and other economic benefits. For firms, understanding the drivers and benefits of clustering is useful for developing a strategy that ensures the firm is well positioned to benefit from clustering.

Technology clusters may span a region as narrow as a city or as wide as a group of neighboring countries[31]. Clusters often encompass an array of industries that are linked through relationships between suppliers, buyers, and producers of complements. One primary reason for the emergence of regional clusters is the benefit of proximity in knowledge exchange. Though advances in information technology have made it easier, faster, and cheaper to transmit information in great distances, several studies indicate that knowledge does not always transfer readily via such mechanisms.

Proximity and interaction can directly influence firms' ability and willingness to exchange knowledge. First, knowledge that is complex or tacit may require frequent and close interaction to be meaningfully exchanged[32]. Firms may need to

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[31] Porter M. E. "Location, competition, and economic development: local clusters in a global economy" Economic Development Quarterly 14, (2000)

[32] Almeida P., Kogut B. "Localization of knowledge and the mobility of engineers in regional networks" Management Science 45, (1999)

interact frequently to develop common ways of understanding and articulating the knowledge before they are able to transfer it[33]. Second, closeness and frequency of interaction can influence a firm's willingness to exchange knowledge. When firms interact frequently, they can develop trust and reciprocity norms. Firms that interact over time develop greater knowledge of each other, and their repeated interactions give them information as to the likelihood of their partner's behaving opportunistically. A shared understanding of the rules of engagement emerges, wherein each partner understands its obligations with respect to how much knowledge is exchanged, how that knowledge can be used, and how the firms are expected to reciprocate[34]. Firms that are proximate thus have an advantage in sharing information that can lead to greater innovation productivity. This can, in turn, lead to other self-reinforcing geographical advantages. A cluster of firms with high innovation productivity can lead to more new firms starting up in the immediate vicinity and can attract other firms to the area[35]. As firms grow, divisions may be spun off into new firms, entrepreneurial employees may start their own enterprises, and supplier and distributor markets emerge to service the cluster. Successful firms also attract new labor to the area and help to make the

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[33] Szulanski G. "Exploring internal stickiness: impediments to the transfer of best practice within the firm" Strategic Management Journal 17, (1996)

[34] Dyer J. H., Nobeoka K. "Creating and managing a high-performance knowledge-sharing network: the Toyota case" Strategic Management Journal 21, (2000)

[35] Stuart T., Sorenson O. "The geography of opportunity: spatial heterogeneity in founding rates and the performance of biotechnology firms" Research Policy 32, (2003)

existing labor pool more valuable by enabling individuals to gain experience working with the innovative firms. The increase in employment and tax revenues in the region can lead to improvements in infrastructure, schools, and other markets that service the population. The benefits firms reap by locating in close geographical proximity to each other are known collectively as **agglomeration economies**.

There are also some downsides to geographical clustering. First, the proximity of many competitors serving a local market can lead competition that reduces their pricing power in their relationships with both buyers and suppliers. Second, the close proximity of firms may increase the likelihood of a firm's competitors gaining access to the firm's proprietary knowledge. Third, clustering can potentially lead to traffic congestion, inordinately high housing costs, and higher concentrations of pollution.

A big part of the reason that technologies are often regionally localized is that technological knowledge is, to a large extent, held by people, and people are often only reluctantly mobile. Studies have indicated that while many innovative activities appear to have some geographic component, the degree to which innovative activities are geographically clustered depends on things such as[36]:

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[36] Schilling M. A. "Strategic management of technological innovation", McGraw-Hill Education, 4th edition, (2012)

- The **nature of the technology**, such as its underlying knowledge base or the degree to which it can be protected by patents or copyright, and the degree to which its communication requires close and frequent interaction;
- **Industry characteristics**, such as the degree of market concentration or stage of the industry life cycle, transportation costs, and the availability of supplier and distributor markets.
- The **cultural context of the technology**, such as the population density of labor or customers, infrastructure development, or national differences in the way techno- logy development is funded or protected.

1.3.4 Technological spillovers

While the work on technology clusters has tended to emphasize the "stickiness" of knowledge, a related body of research has focused on explaining the spread of knowledge across organizational or regional boundaries. This topic is known as technological spillovers. Technological spillovers occur when the benefits from the research activities of one firm spill over to other firms or other entities. Spillovers are thus a positive externality of research and development efforts. Evidence suggests that technology spillovers are a significant influence on innovative activity. Whether R&D benefits will spill over is partially a function of the strength of protection mechanisms such as patents, copyrights, and trade secrets. Since the strength of protection mechanisms varies significantly across industries and countries, the likelihood of spillovers varies also[37]. The likelihood of spillovers is also a function of the nature of the underlying knowledge base and the mobility of the labor pool[38].

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[37] Cohen W., Goto A., Nagata A., Nelson R., Walsh J. "R&D spillovers, patents and the incentives to innovate in japan and the United States" Research Policy 31, (2002)

[38] Almeida P., Kogut B. "Localization of knowledge and the mobility of engineers in regional networks" Management science 45, (1999)

1.4 Types of innovation

Technological innovations are often categorized into different types such as "radical" versus "incremental." Different types of innovation require different kinds of underlying knowledge and have different impacts on the industry's competitors and customers. Four of the dimensions most commonly used to categorize innovations are described here: product versus process innovation, radical versus incremental, competence enhancing versus competence destroying, and architectural versus component.

1.4.1 Product innovation or process innovation

Product innovations are embodied in the outputs of an organization: its goods or services. Process innovations are innovations in the way an organization conducts its business, such as in the techniques of producing or marketing goods or services. Process innovations are often oriented toward improving the effectiveness or efficiency of production by, for example, reducing defect rates or increasing the quantity that may be produced in a given time. For example, a process innovation in a biotechnology firm might entail developing a genetic algorithm that can quickly search a set of disease-related genes to identify a target for therapeutic intervention. In this instance, the innovation process can speed up the firm's ability to develop a product innovation. New product innovations and process innovations often occur in tandem. First, new processes may enable the production of new products. Then, new products may enable the development of new processes. Finally, a product innovation for one firm may simultaneously be a process innovation for another. Though product innovations are often more visible than process innovations, both are extremely important to an organization's ability to compete.

1.4.2 Radical innovation or incremental innovation

One of the primary dimensions used to distinguish types of innovation is the continuum between radical versus incremental innovation. A number of definitions have been posed for radical innovation and incremental innovation, but most hinge on the degree to which an innovation represents a departure from existing practices[39]. Thus radicalness might be conceived as the combination of newness and the degree of differentness. A technology could be new to the world, new to an industry, new to a firm, or new merely to an adopting business unit. A technology could be significantly different from existing products and processes or only marginally different. The most radical innovations would be new to the world and exceptionally different from existing products and processes. The introduction of wireless telecommunication products aptly illustrates that it embodied significantly new technologies that required new manufacturing and service processes. Incremental innovation is at the other end of the spectrum. An incremental innovation might not be particularly new or exceptional, it might have been previously known to the firm or industry, and involve only a minor change from existing practices. The radicalness of innovation is also sometimes defined in terms of risk. Since radical innovations often embody new knowledge,

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[39] Hage J. “Theories of organization” Interscience, (1980)

producers and customers will vary in their experience and familiarity with the innovation, and in their judgment of its usefulness or reliability[40].

Finally, the radicalness of an innovation is relative, and may change over time or with respect to different observers. An innovation that was once considered radical may eventually be considered incremental as the knowledge base underlying the innovation becomes more common. Furthermore, an innovation that is radical to one firm may seem incremental to another. Innovations can also be classified as competence enhancing versus competence-destroying. An innovation is considered to be competence enhancing from the perspective of a particular firm if it builds on the firm's existing knowledge base. An innovation is considered to be competence destroying from the perspective of a particular firm if the technology does not build on the firm's existing competencies or renders them obsolete[41].

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[40] Dewar R. D., Dutton J. E. "The adoption of radical and incremental innovations: an empirical analysis" Management Science32, (1986)

[41] Schilling M. A. "Strategic management of technological innovation" McGraw-Hill Education, 4th edition, (2012)

1.4.3 Architectural innovation or component innovation

Most products and processes are hierarchically nested systems, meaning that at any unit of analysis, the entity is a system of components, and each of those components is, in turn, a system of finer components, until we reach some point at which the components are elementary particles[42]. For example, a bicycle is a system of components such as a frame, wheels, tires, seat, brakes, and so on. Each of those components is also a system of components: the seat might be a system of components that includes a metal and plastic frame, padding, a nylon cover, and so on. An innovation may entail a change to individual components, to the overall architecture within which those components operate, or both. An innovation is considered a component innovation if it entails changes to one or more components, but does not significantly affect the overall configuration of the system[43]. In the example above, an innovation in bicycle seat technology does not require any changes in the rest of the bicycle architecture. In contrast, an architectural innovation entails changing the overall design of the system or the way that components interact with each other. An innovation that is strictly architectural may reconfigure the way that components link together in the

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[42] Simon H. "The architecture of complexity," Proceedings of the American Philosophical Society 106, (1962)

[43] Fleming L., Sorenson O. "Navigating the technology landscape of innovation" Sloan Management Review 44, (2003)

system, without changing the components themselves[44]. Most architectural innovations, however, create changes in the system that reverberate throughout its design, requiring changes in the underlying components in addition to changes in the ways those components interact. Architectural innovations often have far-reaching and complex influences on industry competitors and technology users.

For a firm to initiate or adopt a component innovation may require that the firm have knowledge only about that component. However, for a firm to initiate or adopt an architectural innovation typically requires that the firm have architectural knowledge about the way components link and integrate to form the whole system. Firms must be able to understand how the attributes of components interact, and how changes in some system features might trigger the need for changes in many other design features of the overall system or the individual components.

Though the dimensions described above are useful for exploring key ways that one innovation may differ from another, these dimensions are not independent, nor do they offer a straightforward system for categorizing innovations in a precise and consistent manner. Each of the above dimensions shares relationships with others: for example architectural innovations are often considered more radical and more competence destroying than component innovations.

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[44] Henderson R., Clark K. "Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms" Administrative Science Quarterly 35, (1990)

Furthermore, where an innovation lies on the dimension of competence enhancing versus destroying, architectural versus component, or radical versus incremental depends on the time frame and industry context from which it is considered. Thus, while the dimensions above are valuable for understanding innovation, they should be considered relative dimensions whose meaning is dependent on the context in which they are used[45].

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[45] Schilling M. A. “Strategic management of technological innovation” McGraw-Hill Education, 4th edition, (2012)

1.5 Patterns of performance and technology innovation

Numerous studies of innovation have revealed recurring patterns in how new technologies emerge, evolve, are adopted, and are displaced by other technologies.

Both the rate of a technology's performance improvement and the rate at which the technology is adopted in the marketplace repeatedly have been shown to conform to an s-shape curve. Though s-curves in technology performance and s-curves in technology diffusion are related, they are fundamentally different processes. S-curves in technology diffusion are often explained as a process of different categories of people adopting the technology at different times. Hereafter is proposed some categories of consumers depending on the time of adoption:

1. **Innovators:** are the first individuals to adopt an innovation. Extremely adventurous in their purchasing behavior, they are comfortable with a high degree of complexity and uncertainty. Innovators typically have access to substantial financial resources. Though they are not always well integrated into a particular social system, innovators play an extremely important role in the diffusion of an innovation because they are the individuals who bring new ideas into the social system.
2. **Early adopters:** The second category of adopters is the early adopters. Early adopters are well integrated into their social system and have the greatest potential for opinion leadership. Early adopters are respected by their peers

and know that to retain that respect they must make sound innovation adoption decisions. Other potential adopters look to early adopters for information and advice, thus early adopters make excellent missionaries for new products or processes.

3. **Early majority:** adopts innovations slightly before the average member of a social system. They are typically not opinion leaders, but they interact frequently with their peers.
4. **Late majority:** Like the early majority, the late majority constitutes one-third of the individuals in a social system. Those in the late majority approach innovation with a skeptical air and may not adopt the innovation until they feel pressure from their peers. The late majority may have scarce resources, thus making them reluctant to invest in adoption until most of the uncertainty about the innovation has been resolved.
5. **Laggards:** They may base their decisions primarily upon past experience rather than influence from the social network, and they possess almost no opinion leadership. They are highly skeptical of innovations and innovators, and they must feel certain that a new innovation will not fail before adopting it.

1.5.1 Patterns S-curves in Technological development

Many technologies exhibit an s-curve in their performance improvement over their lifetimes[46]. When a technology's performance is plotted against the amount of effort and money invested in the technology, it typically shows slow initial improvement, then accelerated improvement, then diminishing improvement. Performance improvement in the early stages of a technology is slow because the fundamentals of the technology are poorly understood. Great effort may be spent exploring different paths of improvement or different drivers of the technology's improvement. If the technology is very different from previous technologies, there may be no evaluation routines that enable researchers to assess its progress or its potential. Furthermore, until the technology has established a degree of legitimacy, it may be difficult to attract other researchers to participate in its development[47]. However, as scientists or firms gain a deeper understanding of the technology, improvement begins to accelerate. The technology begins to gain legitimacy as a worthwhile endeavor, attracting other developers. Furthermore, measures for assessing the technology are developed, permitting researchers to target their attention toward those activities that reap the greatest improvement per unit of effort, enabling performance to increase rapidly. However, at some point, diminishing returns to effort begin to set in. As the technology begins to reach its

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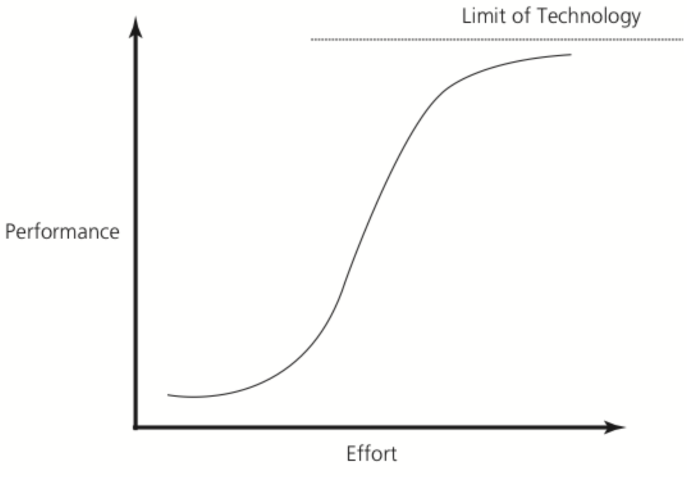
[46] Foster R. "Innovation: the attacker's advantage" Summit Books, (1986)

[47] Garud R., Rappa M. A. "A socio-cognitive model of technology evolution: the case of cochlear implants" Organization Science 5, (1994)

inherent limits, the cost of each marginal improvement increases, and the s-curve flattens. Often a technology's s-curve is plotted with performance against time, but this must be approached with care. If the effort invested is not constant over time, the resulting s-curve can obscure the true relationship. If effort is relatively constant over time, plotting performance against time will result in the same characteristic curve as plotting performance against effort. However, if the amount of effort invested in a technology decreases or increases over time, the resulting curve could appear to flatten much more quickly, or not flatten at all. Technologies do not always get the opportunity to reach their limits; they may be rendered obsolete by new, discontinuous technologies.

Fig. 1.2 S-curve of technology development



A new innovation is discontinuous when it fulfills a similar market need, but does so by building on an entirely new knowledge base[48].

In early stages, effort invested in a new technology may reap lower returns than effort invested in the current technology, and firms are often reluctant to switch. However, if the disruptive technology has a steeper s-curve or an s-curve that increases to a higher performance limit (see Figure 1.2), there may come a time when the returns to effort invested in the new technology are much higher than effort invested in the incumbent technology. New firms entering the industry are likely to choose the disruptive technology, and incumbent firms face the difficult choice of trying to extend the life of their current technology or investing in switching to the new technology. If the disruptive technology has much greater performance potential for a given amount of effort, in the long run it is likely to displace the incumbent technology, but the rate at which it does so can vary significantly.

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[48] Foster R. "Innovation: the attacker's advantage" Summit Books, (1986)

1.5.2 Patterns S-curves in Technology expansion

S-curves are also often used to describe the diffusion of a technology. Unlike s-curves in technology performance in technology diffusionare obtained by plotting the cumulative number of adopters of the technology against time. This yields an s-shape curve because adoption is initially slow when an unfamiliar technology is introduced to the market, it accelerates as the technology becomes better understood and utilized by the mass market, and eventually the market is saturated so the rate of new adoptions declines. For instance, when electronic calculators were introduced to the market, they were first adopted by the relatively small pool of scientists and engineers. This group had previously used slide rules. Then the calculator began to penetrate the larger markets of accountants and commercial users, followed by the still larger market that included students and the general public. After these markets had become saturated, fewer opportunities remained for new adoptions[49]. One rather curious feature of technology diffusion is that it typically takes far more time than information diffusion[50].

If a new technology is a significant improvement over existing solutions, why do some firms shift to it more slowly than others? The answer may lie in the complexity of the knowledge underlying new technologies and in the development of complementary resources that make those technologies useful.

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[49] Brown R. “Managing the ‘s’ curves of innovation” Journal of Consumer Marketing 9, (1992).

[50] Rogers E. “Diffusion of innovations” Free Press, (1995).

Although some of the knowledge necessary to utilize a new technology might be transmitted through manuals or other documentation, other aspects of knowledge necessary to fully realize the potential of a technology might be built up only through experience. Some of the knowledge about the technology might be tacit and require transmission from person to person through extensive contact. Many potential adopters of a new technology will not adopt it until such knowledge is available to them, despite their awareness of the technology and its potential advantages[51].

Furthermore, many technologies become valuable to a wide range of potential users only after a set of complementary resources are developed for them.

Finally, it should be clear that the s-curves of diffusion are in part a function of the s-curves in technology improvement: as technologies are better developed, they become more certain and useful to users, facilitating their adoption. Furthermore, as learning- curve and scale advantages accrue to the technology, the price of finished goods often drops, further accelerating adoption by users.

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[51] Geroski P. A. "Models of technology diffusion," Research Policy 29, (2000)

1.5.3 Patterns S-curves as a predicting tool

Several authors have argued that managers can use the s-curve model as a tool for predicting when a technology will reach its limits and as a prescriptive guide for whether and when the firm should move to a new, more radical technology[52]. Firms can use data on the investment and performance of their own technologies, or data on the overall industry investment in a technology and the average performance achieved by multiple producers. Managers could then use these curves to assess whether a technology appears to be approaching its limits or to identify new technologies that might be emerging on s-curves that will intersect the firm's technology s-curve. Managers could then switch s-curves by acquiring or developing the new technology. However, as a prescriptive tool, the s-curve model has several serious limitations. First, it is rare that the true limits of a technology are known in advance, and there is often considerable disagreement among firms about what a technology's limits will be. Second, the shape of a technology's s-curve is not set in stone. Unexpected changes in the market, component technologies, or complementary technologies can shorten or extend the life cycle of a technology. Furthermore, firms can influence the shape of the s-curve through their development activities. For example, firms can sometimes

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[52] Foster R. "Innovation: the attacker's advantage" Summit Books, (1986)

stretch the s-curve through implementing new development approaches or revamping the architecture design of the technology[53].

Finally, whether switching to a new technology will benefit a firm depends on a number of factors, including the advantages offered by the new technology, the new technology's fit with the firm's current abilities, the new technology's fit with the firm's position in complementary resources, and the expected rate of diffusion of the new technology. Thus, a firm that follows an s-curve model too closely could end up switching technologies earlier or later than it should.

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[53] Christensen C. "Innovation and the general manager" Irwin/McGraw-Hill, (1999)

1.5.4 Cyclical changes

The s-curve model above suggests that technological change is cyclical: Each new s-curve user in an initial period of turbulence, followed by rapid improvement, then diminishing returns, and ultimately is displaced by a new technological discontinuity[54]. The emergence of a new technological discontinuity can overturn the existing competitive structure of an industry, creating new leaders and new losers. Schumpeter called this process creative destruction, and argued that it was the key driver of progress in a capitalist society[55].

Several studies have tried to identify and characterize the stages of the technology cycle in order to better understand why some technologies succeed and others fail, and whether established firms or new firms are more likely to be successful in introducing or adopting a new technology[56]. One technology evolution model that rose to prominence was proposed by Utterback and Abernathy[57]. They observed that a technology passed through distinct phases. In the first phase there was considerable uncertainty about both the technology and its market. Products or services based on the technology might be crude, unreliable, or expensive, but might suit the needs of some market niches. In this phase, firms experiment with

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[54] Anderson P., Tushman M., "Technological discontinuities and dominant designs: a cyclical model of technological change" Administrative Science Quarterly 35, 1990).

[55] Schumpeter J. "Capitalism, socialism and democracy" Harper Brothers, (1942).

[56] Sahal D. "Patterns of technological innovation" Addison-Wesley Publishing, (1981).

[57] Utterback J.M. Abernathy W.J. "A dynamic model of process and product innovation" Omega 3, (1975).

different form factors or product features to assess the market response. Eventually, however, producers and customers begin to arrive at some consensus about the desired product attributes, and a *dominant design* emerges. The dominant design establishes a stable architecture for the technology and enables firms to focus their efforts on process innovations that make production of the design more effective and efficient or on incremental innovations to improve components within the architecture. Utterback and Abernathy termed this phase the *specific phase* because innovations in products, materials, and manufacturing processes are all specific to the dominant design.

In the words of Anderson and Tushman, the rise of a dominant design signals the transition from the era of ferment to the *era of incremental change*[58]. In this era, firms focus on efficiency and market penetration. Firms may attempt to achieve greater market segmentation by offering different models and price points. They may also attempt to lower production costs by simplifying the design or improving the production process. This period of accumulating small improvements may account for the bulk of the techno- logical progress in an industry, and it continues until the next technological discontinuity. Understanding the knowledge that firms develop during different eras lends insight into why successful firms often resist the transition to a new technology,

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[58] Anderson P. Tushman M. “Technological discontinuities and dominant designs: a cyclical model of technological change” Administrative Science Quarterly 35, (1990)

even if it provides significant advantages. During the era of incremental change, many firms cease to invest in learning about alternative design architectures and instead invest in refining their competencies related to the dominant architecture.

Most competition revolves around improving components rather than altering the architecture, thus, companies focus their efforts on developing component knowledge and knowledge related to the dominant architecture. As firms' routines and capabilities become more and more wedded to the dominant architecture, the firms become less able to identify and respond to a major architectural innovation. For example, the firm might establish divisions based on the primary components of the architecture and structure the communication channels between divisions on the basis of how those components interact. In the firm's effort to absorb and process the vast amount of information available, it is likely to establish filters that enable it to identify the information most crucial to its understanding of the existing technology design[59].

As the firm's expertise, structure, communication channels, and filters all become oriented around maximizing its ability to compete in the existing dominant design, they become barriers to the firm's recognizing and reacting to a new technology architecture. While many industries appear to conform to this model in which a dominant de- sign emerges, there are exceptions. In some industries,

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[59] Henderson R., Clark K. "Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms" Administrative Science Quarterly, 35 (1990).

heterogeneity of products and production processes are a primary determinant of value, and thus a dominant design is undesirable[60].

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[60] Porter M. E. “The technological dimension of competitive strategy” Research on technological innovation, management and policy, JAI Press, (1983)

1.6 Timing of adoption

In the previous paragraph we discuss that industries are characterized by increasing returns to adoption, meaning that the more a technology is adopted, the more valuable it becomes. In such industries, timing can be crucial: a technology that is adopted earlier than others may reap self-reinforcing advantages such as greater funds to invest in improving the technology, greater availability of complementary goods, and less customer uncertainty. On the other hand, the same factors that cause increasing returns to adoption may make very early technologies unattractive: if there are few users of the technology or availability of complementary goods is poor, the technology may fail to attract customers. A number of other first-mover advantages, and disadvantages, can shape how timing of entry is related to likelihood of success. Entrants are often divided into three categories: first movers, which are the first to sell in a new product or service category; early followers, which are early to the market but not first; and late entrants, which enter the market when or after the product begins to penetrate the mass market. The research on whether it is better to be a first mover, early follower, or late entrant yields conflicting conclusions. Some studies that contrast early entrants with late entrants find that early entrants have higher returns and survival rates, consistent with the notion of first-mover advantage[61]. However, other research has suggested the first firm to market is often the first to fail,

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[61] Agarwal R. “Technological activity and survival of firms” Economics Letters 52, (1996)

causing early followers to outperform first movers[62]. Still other research contends the higher returns of being a first mover typically offset the survival risk[63]. A number of factors influence how timing of entry affects firm survival and profits.

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[62] Golder P., Tellis G. “Pioneer advantage: marketing logic or marketing legend?” Journal of Marketing Research 30, (1993)

[63] Robinson W., Sungwook M. “Is the first to market the first to fail? empirical evidence for industrial goods businesses” Journal of Marketing Research 39, (2002)

1.6.1 First-mover advantages

One of the key factors influencing the level of profits for companies is the ability to launch the product "at the right time" on the market. The management can choose to be the first-mover can pursue the following advantages[64]:

a) **Brand loyalty and technological leadership**: The company that introduces a new technology may earn a long-lasting reputation as a leader in that technology domain. Such a reputation can help sustain the company's image, brand loyalty, and market share even after competitors have introduced comparable products. The organization's position as technology leader also enables it to shape customer expectations about the technology's form, features, pricing, and other characteristics. By the time later entrants come to market, customer requirements may be well established. If aspects that customers have come to expect in a technology are difficult for competitors to imitate (e.g., if they are protected by patent or copyright, or arise from the first mover's unique capabilities), being the technology leader can yield sustained **monopoly rents**. Even if the technology characteristics are imitable, the first mover has an opportunity to build brand loyalty before the entry of other competitors.

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[64] Schilling M. A. "Strategic management of technological innovation" McGraw-Hill Education, 4th edition (2012)

b) **Preemption of scarce assets**: Firms that enter the market early can preemptively capture scarce resources such as key locations, government permits, access to distribution channels, and relationships with suppliers.

c) **Exploiting buyer switching costs**: Once buyers have adopted a good, they often face costs to switch to another good. For example, the initial cost of the good is itself a switching cost, as is the cost of complements purchased for the good. Additionally, if a product is complex, buyers must spend time becoming familiar with its operation; this time investment becomes a switching cost that deters the buyer from switching to a different product. If buyers face switching costs, the firm that captures customers early may be able to keep those customers even if technologies with a superior value proposition are introduced later.

d) **Reaping increasing returns advantages**: In an industry with pressures encouraging adoption of a dominant design, the timing of a firm's investment in new technology development may be particularly critical to its likelihood of success.

1.6.2 First-mover disadvantages

Despite the great attention that first-mover advantages receive, there are also arguments for not entering a market too early. Many studies have found that first movers earn greater revenues than other entrants, but that they also face higher costs, causing them to earn significantly lower profits in the long run[65]. First movers typically bear the bulk of the research and development expenses for their product or service technologies, and they must also often pay to develop suppliers and distribution channels, plus consumer awareness. A later entrant often can capitalize on the research and development investment of the first mover, fine-tune the product to customer needs as the market becomes more certain, avoid any mistakes made by the earlier entrant, and exploit incumbent inertia[66]. Later entrants can also adopt newer and more efficient production processes while early movers are either stuck with earlier technologies or must pay to rebuild their production systems[67].

Hereafter is proposed a summary of the disadvantages in which the first-mover can run into[68]:

a) **Research and development expenses**: Developing a new technology often entails significant research and development expenses, and the first to develop

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[65] Boulding W., Christen M. "First-mover disadvantage" Harvard Business Review, (2001)

[66] Lieberman M., Montgomery D. "First mover advantages: a survey" Strategic Management Journal9, (1988)

[67] Boulding W., Christen M. "First-mover disadvantage" Harvard Business Review, (2001)

[68] Schilling M. A. "Strategic management of technological innovation" McGraw-Hill Education, 4th edition, (2012)

and introduce a technology typically bears the brunt of this expense. By the time a firm has successfully developed a new technology, it may have borne not only the expense of that technology but also the expense of exploring technological paths that did not yield a commercially viable product. This firm also typically bears the cost of developing necessary production processes and complementary goods that are not available on the market. Since the new product development failure rate can be as high as 95 percent, being the first to develop and introduce an unproven new technology is expensive and risky. By contrast, later entrants often do not have to invest in exploratory research. Once a product has been introduced to the market, competitors can often ascertain how the product was created. The later entrant can also observe the market's response to particular features of the technology and decide how to focus its development efforts. Thus, the later entrant can both save development expense and produce a product that achieves a closer fit with market preferences.

b) **Undeveloped supply and distribution channels**: When a firm introduces a new-to-the-world technology, often no appropriate suppliers or distributors exist. The firm may face the daunting task of developing and producing its own supplies and distribution service, or assisting in the development of supplier and developer markets.

c) **Immature enabling technologies and complements**: When firms develop technologies, they often rely on other producers of enabling technologies. Furthermore, many products may also require complementary goods to be useful or valuable. When new technologies are introduced to a market, important complements may not yet be fully developed, thus hindering adoption of the innovation. Therefore, a lack of complementary technologies and infrastructure can pose serious obstacles for early movers.

d) **Uncertainty of customer requirements:** A first mover to the market may face considerable uncertainty about what product features customers will ultimately desire and how much they will be willing to pay for them. For a very new product technology, market research may be of little help. Customers may have little idea of the value of the technology or the role it would play in their lives. As a consequence, first movers may find that their early product offerings must be revised as the market begins to reveal customer preferences. First movers have an opportunity to shape customer preferences by establishing the precedent for product design in the newly emerging market and by investing in customer education. Customer education efforts are expensive, however. If the product is slow to begin to reap revenues for the sponsoring firm, it may collapse under the weight of its R&D and marketing expenses.

1.6.3 Remarks on timing of entry

In early market stages, a technology may be underdeveloped and its fit with customer needs unknown. In late market stages, a technology may be well understood, but competitors may have already captured controlling shares of the market. How does a firm decide whether to attempt to pioneer a technology category or to wait while others do so? Below some considerations:

- **Customer certainty:** When new-to-the-world technologies are first developed, customers may have difficulty understanding the technology and its role in their life. Both producers and customers may face considerable ambiguity about the importance of various features of the technology. As producers and customers gain experience with the technology, features that initially seemed compelling may turn out to be unnecessary, and features that had seemed unimportant may turn out to be crucial. Not all pioneers face customer uncertainty: some innovations are developed in response to well-understood customer needs. Customer requirements may have been long known even if the method of meeting them was not.
- **Improvement that innovation provide:** The degree to which the technology represents an improvement over previous technologies increases a firm's likelihood of successful early entry. That is, when a technology makes a dramatic improvement over previous generations or different technologies that serve similar functions, it will more rapidly gain customer acceptance. There

will be less ambiguity about the value of the technology and more early adoptions, as a consequence, customer expectations should become known sooner, and adoptions should be more rapid[69].

- **Maturity of enabling technologies:** As mentioned earlier, many innovations rely on crucial enabling technologies to ensure their performance. A high-definition television set is of little value if networks are incapable of broadcasting in high definition; cellular phones or portable stereos would have little value if small and long-lasting batteries were unavailable. A developer must identify which enabling technologies will affect the performance of the new innovation and assess the degree to which those technologies are mature enough to deliver the desired performance. More mature enabling technologies allow earlier entry; less mature enabling technologies may favor waiting for enabling technologies to be further developed.
- **Complementary goods:** If the value of an innovation hinges critically on the availability and quality of complementary goods, then the state of complementary goods determines the likelihood of successful entry. Not all innovations require complementary goods, and many more innovations can utilize existing complementary goods. If, on the other hand, the innovation

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[69] Min S., Kalwani M.U., Ronson W.T. “Market pioneer and early follower survival risks: a contingency analysis of really new versus incrementally new product markets” Journal of Marketing 70, (2006)

requires the development of new complementary goods, then a pioneer must find a way to ensure their availability. Some firms have the resources and capabilities to develop both a good and its complements, while others do not. If the firm's innovation requires complementary goods that are not available on the market, and the firm is unable to develop those complements, successful early entry is unlikely.

- **Threat of competitive entry:** If there are significant entry barriers or few potential competitors with the resources and capabilities to enter the market, the firm may be able to wait while customer requirements and the technology evolve. Over time, one would expect customer expectations to become more certain, enabling technologies to improve, and support goods and services to be developed, thus increasing the likelihood that sponsored technologies will possess a set of attributes that meet consumer demands. However, if the technology proves to be valuable, other firms are also likely to be attracted to the market. Thus, if entry barriers are small, the market could quickly become quite competitive, and entering a market that has already become highly competitive can be much more challenging than entering an emerging market[70]. Margins may already have been driven down to levels that require competitors to be highly efficient, and access to distribution channels may be

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[70] Makadok R. "Can first-mover and early-mover advantages be sustained in an industry with low barriers to entry/imitation?" Strategic Management Journal 19, (1998)

limited. If the threat of competitive entry is high, the firm may need to enter earlier to establish brand image, capture market share, and secure relationships with suppliers and distributors.

- **Increasing returns to adoption:** In industries that have increasing returns to adoption due to strong learning curve effects or network externalities, allowing competitors to get a head start in building an installed base can be very risky. If a competitor's offering builds a significant installed base, the cycle of self-reinforcing advantages could make it difficult for the firm to ever catch up. Furthermore, if there are forces encouraging adoption of a single dominant design, a competitor's technology may be selected. If protection mechanisms such as patents prevent the firm from offering a compatible technology, the firm may be locked out[71].
- **Withstand to early losses:** A first mover often bears the bulk of the expense and risk of developing and introducing a new innovation. First movers thus often need significant amounts of capital that either is available internally or can be accessed externally. Furthermore, the first mover must be able to withstand a significant period with little sales revenue from the product. Even in the case of successful new technologies, often a considerable period elapses between the point at which a first mover introduces a new innovation and the

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[71] Schilling M.A. "Technological lock out: an integrative model of the economic and strategic factors driving technology success and failure" Academy of Management Review 23, (1998)

point at which the innovation begins to be adopted by the mass market. The s-curve shape of technology diffusion illustrates this aptly. New innovations tend to be adopted very slowly at first, while innovators and early adopters try the technology and communicate their experience to others. This slow initial takeoff of new innovations has caused the demise of many start-up firms. On the other hand, firms with significant resources also may be able to more easily catch up to earlier entrants[72]. By spending aggressively on development and advertising, and leveraging relationships with distributors, a late entrant may be able to rapidly build brand image and take market share away from earlier movers.

- **Resources to accelerate market acceptance:** A firm with significant capital resources not only has the capability to withstand a slow market takeoff, but also can invest such resources in accelerating market take-off. The firm can invest aggressively in market education, supplier and distributor development, and development of complementary goods and services. Each of these strategies can accelerate the early adoption of the innovation, giving the firm much greater discretion over entering early[73].

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[72] Shamsie J., Phelps C., Kuperman J. “Better late than never: a study of late entrants in household electrical equipment” Strategic Management Journal 25, (2003)

[73] Schilling M. A. “Technological leapfrogging: lessons from the U.S. video game console industry,” California Management Review 45, (2003)

- **Firm's reputation:** In addition to capital resources, a firm's reputation and credibility can also influence its optimal timing of entry[74]. A firm's reputation can send a strong signal about its likelihood of success with a new technology. Customers, suppliers, and distributors will use the firm's track record to assess its technological expertise and market prowess. Customers may use the firm's reputation as a signal of the innovation's quality, and thus face less ambiguity about adopting the innovation. A firm with a well-respected reputation for successful technological leadership is also more likely to attract sup- pliers and distributors[75].

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[74] Shepherd D. A., Shanley M. "New venture strategy: timing, environmental uncertainty and performance" Sage, (1998)

[75] Schilling M. A. "Technological leapfrogging: lessons from the U.S. video game console industry," California Management Review 45, (2003)

1.7 Evaluating innovation projects

Developing innovative new products and services is expensive and time-consuming. It is also extremely risky: most studies have indicated that the vast majority of development projects fail[76]. Firms have to make difficult choices about which projects are worth the investment, and then they have to make sure those projects are pursued with a rigorous and well-thought-out development process.

While many project valuation methods seem to assume that all valuable projects will be funded, most firms face serious constraints in capital and other resources, forcing them to choose between multiple valuable projects. Many firms use a form of capital rationing in formulating their new product development plans. Under capital rationing, the firm sets a fixed research and development budget, and then uses a rank ordering of possible projects to determine which will be funded. Firms might establish this budget on the basis of industry benchmarks or historical benchmarks of the firm's own performance. The rank ordering used in capital rationing may be established by any number of methods, including quantitative methods, such as discounted cash flow analysis or options analysis, or qualitative methods, such as screening questions and portfolio mapping, or a combination of multiple methods. Knowing the requirements, strengths, and

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[76] Schilling M. A. "Strategic management of technological innovation", McGraw-Hill Education, 4th edition, (2012)

weaknesses of each method helps managers make sound decisions about which valuation techniques to employ.

1.7.1 Quantitative methods

Quantitative methods of analyzing new projects usually entail converting projects into some estimate of future cash returns from a project. Quantitative methods enable managers to use rigorous mathematical and statistical comparisons of projects, though the quality of the comparison is ultimately a function of the quality of the original estimates. The accuracy of such estimates can be questionable—particularly in highly uncertain or rapidly changing environments. The most commonly used quantitative methods include discounted cash flow methods and real options, that are summarized below:

1. **Discounted cash flow methods**: Many firms use some form of discounted cash flow analysis to evaluate projects. Discounted cash flows are quantitative methods for assessing whether the anticipated future benefits are large enough to justify expenditure, given the risks. Discounted cash flow methods take into account the payback period, risk, and time value of money. The two most commonly used forms of discounted cash flow analysis for evaluating investment decisions are **net present value** (NPV) and **internal rate of return** (IRR). Both methods rely on the same basic discounted cash flow mechanics, but they look at the problem from different angles. NPV asks, "Given a particular level of expenditure, particular levels and rate of cash inflows, and a discount rate, what is this project worth today?" IRR asks instead, "Given a particular level of expenditure and particular levels and rate

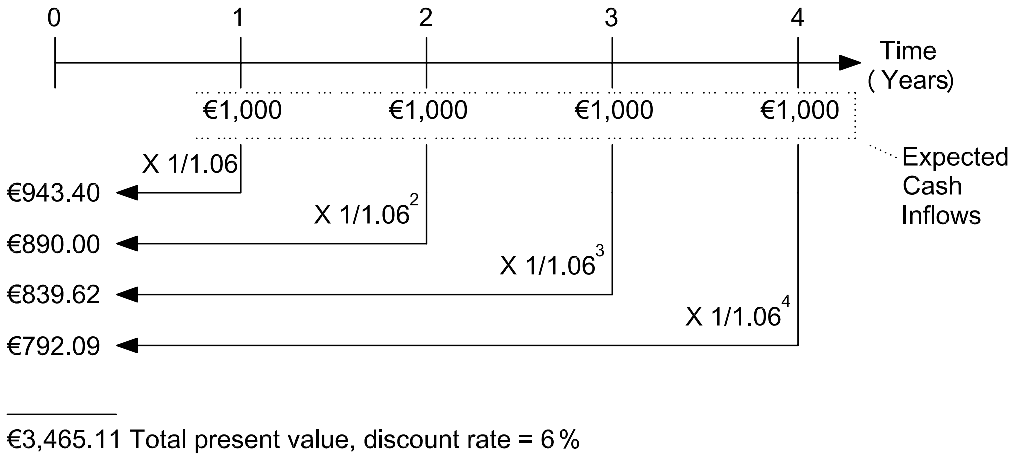
of cash inflows, what rate of return does this project yield?" For either method, managers must use estimates of the size and timing of expenditures and cash inflows. Both methods enable the decision maker to incorporate some basic measure of risk. For example, riskier projects may be examined by using a higher discount factor in NPV analysis. Managers also often calculate discounted cash flow measures using best-case and worst-case cash flow estimates.

a. **Net Present Value (NPV):**To calculate the NPV of a project, managers first estimate the costs of the project and the cash flows the project will yield. Costs and cash flows that occur in the future must be discounted back to the current period to account for risk and the time value of money. The present value of cash inflows can then be compared to the present value of cash outflows:

   NPV = Present value of cash inflow – Present value of cash outflows

   If this value is greater than 0, then the project generates wealth, given the assumptions made in calculating its costs and cash inflows. To find the present value of cash inflow and outflows, each cash flow must be discounted back to the current period using a discount rate. If there is a single expenditure at the beginning of the project (year 0), the original expenditure can be compared directly to the present value of the future expected cash flows. In the example in Figure 1.3 the present value of the future cash flows, given a discount rate of 6 percent, is € 3.465,11.

Fig. 1.3 S-curve of technology development



Thus, if the initial cost of the project were less than the above sum, the net present value of the project is positive. If there are cash outflows for multiple periods those would have to be discounted back to the current period. If the cash inflows from the development project were expected to be the same each year, we can use the formula for calculating the present value of an annuity instead of discounting each of the cash inflows individually. This is particularly useful when cash inflows are expected for many years. The present value of *C* euros per period, for *p*eriods, with discount rate *r* is given by the following formula:

$$\text{Annuity present value} = \frac{1-\{\frac{1}{(1+r)^1}\}}{r}$$

This amount can then be compared to the initial investment. If the cash flows are expected in perpetuity, then a simpler formula can be used:

$$\text{Perpetuity present value} = c \times \frac{1}{r}$$

The present value of the costs and future cash flows can also be used to calculate the **discounted payback period,** that is, the time required to break even on the project using discounted cash flows.

b. **Internal Rate of Return (IRR):** The internal rate of return of a project is the discount rate that makes the net present value of the investment zero. Managers can compare this rate of return to their required return to decide if the investment should be made. Calculating the IRR of a project typically must be done by trial and error, substituting progressively higher interest rates into the NPV equation until the NPV is driven down to zero. Calculators and computers can perform this trial and error. This measure should be used cautiously, however, if cash flows arrive in varying amounts per period, there can be multiple rates of return, and typical calculators or computer programs will often simply report the first IRR that is found. Both net present value and internal rate of return techniques provide concrete financial estimates that facilitate strategic planning and trade-off decisions. They explicitly consider the timing of investment and cash flows, and the time value of money and risk. They can make the returns of the project seem unambiguous, and managers may find them very reassuring. However, this minimization of ambiguity may be deceptive; discounted cash flow estimates are only as accurate as the original estimates of the profits from the technology, and in many situations it is extremely difficult to anticipate the returns of the technology. Furthermore, such methods discriminate heavily against projects that are long term or risky, and the methods may fail to capture the strategic importance of the investment decision. Technology development projects play a crucial role in building and leveraging firm capabilities, and creating options for the future. Investments in new core technologies are investments in the organization's capabilities and learning, and they create opportunities for the firm that might other- wise be unavailable[77]. Thus, standard discounted cash flow analysis has the potential to severely undervalue a development project's contribution to the firm.

2. **Real Options:** When a firm develops new core technologies, it is simultaneously investing in its own learning and in the development of new capabilities. Thus, development projects can create valuable future

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[77] Kogut B., Kulatilaka N. "Options thinking and platform investments: investing in opportunity" California Management Review 36, (1994)

opportunities for the firm that would otherwise be unavailable[78]. Even development projects that appear unsuccessful may prove to be very valuable when they are considered from the perspective of the options they create for the future of the firm. Some managers have begun arguing that new product development decisions should be evaluated as "real options." To understand real options, it is first useful to consider the financial model upon which they are based: stock options. A call option on a stock enables an investor to purchase the right to buy the stock at a specified price in the future. If, in the future, the stock is worth more than the exercise price, the holder of the option will typically exercise the option by buying the stock. If the stock is worth more than the exercise price plus the price paid for the original option, the option holder makes money on the deal. If the stock is worth less than the exercise price, the option holder will typically choose not to exercise the option, allowing it to expire. In this case, the option holder loses the amount of money paid for the initial option. If, at the time the option is exercised, the stock is worth more than the exercise price but not more than the exercise price plus the amount paid for the original option, the stockholder will typically exercise the option. Even though the stockholder loses money on the deal, he or she loses less than if he or she allowed the option to expire. In "real

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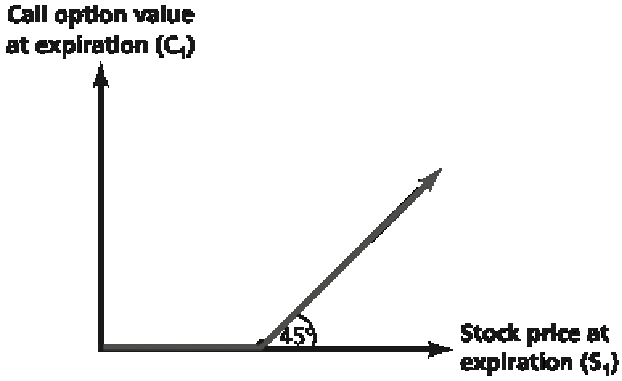
[78] B. Kogut B., Kulatilaka N. "Options thinking and platform investments: investing in opportunity" California Management Review 36, (1994)

options," the assets underlying the value of the option are non-financial resources[79]. An investor who makes an initial investment in basic R&D or in break-through technologies is, it is argued, buying a real call option to implement that technology later should it prove to be valuable[80]. Figure 1.4 provides examples of investment decisions that can be viewed as real call options. With respect to research and development:

- The cost of the R&D program can be considered the price of a call option;
- The cost of future investment required to capitalize on the R&D program can be considered the exercise price;
- The returns to the R&D investment are analogous to the value of a stock purchased with a call option[81].

Fig. 1.4 The value of a call option at expiration



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[79] Miller K. D., Folta T. B. "Option value and entry timing" Strategic Management Journal 23, (2002)

[80] Hurry D., Miller A. T., Bowman E. H. "Calls on high-technology: japanese exploration of venture capital investments in the United States" Strategic Management Journal 13, (1992)

[81] Mitchell G., Hamilton W. "Managing R&D as a strategic option" Research Technology Management 31, (1988)

As shown in Figure 1.4 the value of a call stock option is zero as long as the price of the stock remains less than the exercise price. If the value of the stock rises above the exercise price, however, the value of the call rises with the value of the stock, dollar for dollar[82]. Options are valuable when there is uncertainty, and because technology trajectories are uncertain, an options approach may be useful. Though there has not yet been much empirical work in the area, several authors have developed methodologies and applications of options analysis to valuing technology development investments[83]. Also, some evidence shows that an options approach results in better technology investment decisions than a cash flow analysis approach[84].

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[82] Ross S. A., Westerfield R. W., Jordan B. D. "Fundamentals of corporate finance" Irwin, (1993)

[83] Boer F. P. "Valuation of technology using real options" Research Technology Management 43, (2000)

[84] Benaroch M., Kauffman R. "Justifying electronic banking network expansion using real options analysis" MIS Quarterly 24, (2000)

1.7.2 Qualitative methods

Most new product development projects require the evaluation of a significant amount of qualitative information. Many factors in the choice of development projects are extremely difficult to quantify, or quantification could lead to misleading results. Almost all firms utilize some form of qualitative assessment of potential projects, ranging from informal discussions to highly structured approaches.

Below are summarized some examples of qualitative assessment methods:

- **Screening questions:** As a starting point, a management team is likely to discuss the potential costs and benefits of a project, and the team may create a list of screening questions that are used to structure this discussion. These questions might be organized into categories such as the role of the customer, the role of the firm's capabilities, and the project's timing and cost[85]. After creating a list of questions, managers can use the questions to structure debate about a project, or they can create a scoring mechanism that can then be weighted according to importance and used in subsequent analysis. While screening questions do not always provide concrete answers about whether or not to fund a project, they enable a firm to consider a wider range of issues that may be important in the firm's development decisions.

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[85] Allen K. R. "Bringing new technology to market" Prentice Hall, (2003)

- **Aggregate project planning portfolio:** Many companies find it valuable to map their R&D portfolio according to levels of risk, resource commitment, and timing of cash flows. Managers can use this map to compare their desired balance of projects with their actual balance of projects[86]. It can also help them to identify capacity constraints and better allocate resources[87]. Companies may use a project map to aid this process. Four types of development projects commonly appear on this map:
  - Advanced R&D: are the precursor to commercial development projects and are necessary to develop cutting-edge strategic technologies;
  - Breakthrough: involve development of products that incorporate revolutionary new product and process technologies;
  - Platform: typically offer fundamental improvements in the cost, quality, and performance of a technology over preceding generations;
  - Derivative projects: involve incremental changes in products and/or processes.

  Over time, a particular technology may migrate through these different types of projects. A platform project is designed to serve a core group of

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[86] Wind Y., Mahajan V. "New product development process: a perspective for reexamination" Journal of Product Innovation Management 5, (1988)

[87] Schilling M. A. "Strategic management of technological innovation" McGraw-Hill Education, 4th edition, (2012)

consumers, whereas derivative projects represent modifications of the basic platform design to appeal to different niches within that core group.

Companies that use the project map categorize all their existing projects and projects under consideration by the resources they require and by how they contribute to the company's product line. The company can then map the project types and identify gaps in the development strategy[88]. Managers can also use the map to identify their desired mix of projects, and allocate resources accordingly. The mix of projects represented on such a map should be consistent both with the company's resources, strategic position, and with its strategic intent. Mapping the company's R&D portfolio encourages the firm to consider both short-term cash flow needs and long-term strategic momentum in its budgeting and planning. For instance, a firm that invests heavily in derivative projects that may be immediately commercialized with little risk may appear to have good returns on its R&D investment in the short run, but then be unable to compete when the market shifts to a newer technology. On the other hand, a firm that invests heavily in advanced R&D or breakthrough projects may be on the leading edge of technology, but run into cash flow problems from a lack of revenues generated from recently commercialized platform or derivative projects.

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[88] Wheelwright S. C., Clark K. B. "Creating project plans to focus product development" Harvard Business Review, (1992).

- **Q-Sort:** is a simple method for ranking objects or ideas on a number of different dimensions. The Q-sort method has been used for purposes as diverse as identifying personality disorders to establishing scales of customer preferences. Individuals in a group are each given a stack of cards with an object or idea on each card. In the case of new product development, each card could identify a potential project. Then a series of project selection criteria are presented and for each criterion the individuals sort their cards in rank order or in categories according to that criterion. Individuals then compare their rank orderings and use these comparisons to structure a debate about the projects. After several rounds of sorting and debating, the group is expected to arrive at a consensus about the best projects[89].
- **Conjoint Analysis**: is a family of techniques used to estimate the specific value individuals place on some attribute of a choice, such as the relative value of features of a product or the relative importance of different outcomes of a development project. While individuals may find it very difficult to accurately assess the weight they put on individual attributes of a decision, conjoint analysis enables these weights to be derived statistically. Conjoint analysis enables a subjective assessment of a complex decision to be decomposed into quantitative scores of the relative importance of different criteria. The most common use of conjoint analysis is to assess the relative

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[89] Allen K. R. “Bringing new technology to market” Prentice Hall, (2003)

importance to customers of different product attributes: these values can then be used in development and pricing decisions.

- **Data Envelopment Analysis (DEA):** is a method of assessing a potential project using multiple criteria that may have different kinds of measurement units[90]. For instance, for a particular set of potential projects, a firm might have cash flow estimates, a ranking of the project's fit with existing competencies, a ranking of the project's potential for building desired future competencies, a score for its technical feasibility, and a score for its customer desirability. Each of these measures captures something that is qualitatively different, and the numbers assigned to them arebased on different units of measure. While the first measure is in euros and is a nearly continuous measure, the second two measures are rank orders and thus are categorical measures with little information about what the difference is between one level of rank and another. The last two measures are scores that might be based on a ranking system or scaling system. Data envelopment analysis uses linear programming to combine these different measures from the projects to create a hypothetical *efficiency frontier* that represents the best performance on each measure. It then measures the distance of each project from this frontier to give it an efficiency value. These values can then be used to rank-

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[90] Charnes A. W., Cooper W., Rhodes E. "Measuring the efficiency of decision making units" European Journal of Operational Research 2, (1978)

order the projects or identify projects that clearly dominate others[91].The biggest advantage of DEA is that it enables comparisons of projects using multiple kinds of measures. However, just as with several of the methods described previously, the results of DEA are only as good as the data utilized. Managers bear the responsibility of determining which measures are most important to include and of ensuring that the measures are accurate.

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[91] Linton J. D., Walsch S. T., Morabito J. "Analysis, ranking and selection of R&D projects in a portfolio" R&D Management 32, (2002)

1.8 Technological innovation in material science

Materials have always been an integral part of human civilization and social development, e.g. we designate periods in the past as the stone, Bronze and Iron ages. Recent advances in technologies rely on sophisticated materials: all of them used devices, products, and systems that consist of materials. With the rapid advances in computer technology, design engineering has become quite sophisticated. Materials that are used by us are in one form or another: some in their pure elemental form, some in the form of alloys and compounds and some as composites. The selection of materials and most appropriate manufacturing process depends on several factors, but the most important considerations are shape complexity and properties of material. However, the properties of materials are ultimately linked with the microstructure and processing.

Many times, a materials problem is one of selecting the right material from many thousands that are available. There are several criteria on which the final decision is normally based. First of all, the conditions must be characterized, for these will dictate the properties required of the material. However, rarely does a material possess the maximum or ideal combination of properties. Clearly, it may be necessary to trade off one characteristic for another.

The second consideration in the selection of a material is any deterioration of material properties that may occur during service operation, e.g. significant reductions in mechanical strength may result from exposure to elevated temperatures or corrosive environments.

Finally, probably the overriding consideration is the cost. A material may have the ideal set of properties but could be prohibitively expensive. Obviously, some compromise will have to be made.

1.8.1 Classification of materials

Based on chemical make up and atomic structure, solid materials have been conveniently grouped into three basic categories: *metals, ceramics* and *polymers*. Most materials fall into one distinct grouping or another, although there are also some intermediates. In addition to these, there are also three other groups of important engineering materials: *composites, semiconductors* and *biomaterials.* There are also *advanced materials* utilized in high-technology. Recently, a group of new and state- of-the art materials called as *smart* materials being developed. Very recently, scientists have developed *nano-engineering materials*. A brief description of the material types and representative characteristics are:[92]

1. **Metals:** Normally metallic materials are combinations of metallic elements. Metallic materials have large number of *nonlocalized electrons*, *i.e.* electrons are not bound to particular atoms. Many properties of metals are directly attributable to these electrons. All metals are characterized by metallic properties, *e.g.* luster, opacity, malleability, ductility and electrical conductivity. Although metals compose about three fourth of the known elements but few find service in their pure form. The desired properties for engineering purposes are often found in *alloys.* Typical examples of metallic materials are iron, aluminium, copper, zinc, etc. and their alloys. They can be

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[92] Ashby M., Shercliff H., Cebon D.” Materials. Engineering, Science, Processing and Design” Butterworth-Heinemann, (2007); Callister W.D. "Materials Science and Engineering: An Introduction" John Wiley and Sons, (2007)

used either in bulk or powder form. Metals are extremely good conductors of electricity and heat are not transparent to visible light; a polished metal surface has a lustrous appearance. Moreover, metals are quite strong, yet deformable, which accounts for their extensive use in structural applications. Metallic materials are always crystalline in nature. Scientists have developed *amorphous* alloys by very rapid cooling of a melt or by very high-energy mechanical *miling*. Recently, scientists have developed materials through rapid solidification called as *quasicrystals.* These are neither crystalline nor amorphous, but form an ordered structure somewhere between two known structures. These materials are expected to exhibit far reaching electrical properties.

2. **Alloy:** is a mixture of metals or a mixture of a metal and another element. Alloys are defined by a metallic bonding character. An alloy may be a solid solution of metal elements or a mixture of metallic phases. Intermetallic compounds are alloys with a defined stoichiometry and crystal structure. Alloys are used in a wide variety of applications. In some cases, a combination of metals may reduce the overall cost of the material while preserving important properties. In other cases, the combination of metals imparts synergistic properties to the constituent metal elements such as corrosion resistance or mechanical strength. Examples of alloys are steel, solder, brass, pewter, duralumin, bronze and amalgams. The alloy constituents

are usually measured by mass percentage for practical applications, and in atomic fraction.

3. **Ceramics:** These are crystalline compounds between metallic and non-metallic elements. They are most frequently oxides, nitrides and carbides. Nowadays graphite is also categorized in ceramics. The wide range of materials which falls within this classification include ceramics that are composed of clay minerals, cement and glass. Glass is grouped with this class because it has similar properties but most glasses are *amorphous*. Ceramics are characterized by high hardness, abrasion resistance, brittleness and chemical inertness. Ceramics are typically insulative to the passage of electricity and heat, and are more resistant to high temperatures and harsh environments than metals and polymers. With regard to mechanical behavior, these materials are hard but very brittle. These materials are widely categorized into oxide and non-oxide ceramics.
4. **Polymers:** Many of these are organic substances and derivatives of carbon and hydrogen. Polymers include the familiar plastic and rubber materials. Usually polymers are classified into three categories: *thermoplastic* polymers, *thermosetting* polymers and elastomers, better called as rubbers. Polymers have very large molecular structures. Most plastic polymers are light in weight and are soft in comparison to metals. Polymer materials have typically low densities and may be extremely flexible and widely used as insulators, both

thermal and electrical. Few examples of polymers are polyesters, phenolics, polyethylene, nylon and rubber. The overriding consideration of the selection of a given polymer is whether or not the material can be processed into the required article easily and economically.

5. **Composites:** A composite is a composition of two or more materials in the first three categories, e.g. metals, ceramics and polymers, that has properties from its constituents. Large number of composite materials have been engineered. Fibre glass is a most familiar composite material, in which glass fibres are embedded within a polymeric material. A composite is designed to display a combination of the best characteristics of each of the component materials. Fibre glass acquires strength from the glass and the flexibility from the polymer. A true composite structure should show matrix material completely surrounding its reinforcing material in which the two phases act together to exhibit desired characteristics. These materials as a class of engineering material provide almost an unlimited potential for higher strength, stiffness, and corrosion resistance over the ‘pure’ material systems of metals, ceramics and polymers. Many of the recent developments of materials have involved composite materials. Probably, the composites will be the steels of this century. Nowadays, the rapidly expanding field of nanocomposites is generating many exciting new materials with novel properties. The general class of nanocomposite organic or inorganic material is a fast-growing field of

research. Significant efforts are going on to obtain control of nanocomposite materials depend not only on the properties of their individual parents but also on their morphology and interfacial characteristics. The lamellar class of intercalated organic/inorganic nanocomposites and namely those systems that exhibit electronic properties in at least one of the composites offers the possibility of obtaining well-ordered systems some of which may lead to unusual electrical and mechanical properties. Polymer-based nanocomposites are also being developed for electronic applications such as thin-film capacitors in integrated circuits and solid polymer electrolytes for batteries. No doubt, the field of nanocomposites is of broad scientific interest with extremely impressive technological promise.

6. **Glasses*:*** are non-crystalline solids. The commonest are the soda-lime and borosilicate glasses familiar as bottles and Pyrex ovenware, but there are many more. The lack of crystal structure suppresses plasticity, so, like ceramics, glasses are hard and remarkably corrosion resistant. They are excellent electrical insulators and, of course, they are transparent to light. But like ceramics, they are brittle and vulnerable to stress concentrations.
7. **Semiconductors:** these materials have electrical properties that are intermediate between electrical conductors and insulators. Moreover, the electrical characteristics of semiconducting materials are extremely sensitive to the presence of minute concentrations of impurity atoms; these

concentrations may be controlled over very small spatial regions. Silicon, Germanium and compounds form the vast majority of semiconducting crystals. These semiconducting materials are used in a number of solid state devices, *e.g.* diodes, transistors, photoelectric devices, solar batteries, radiation detectors, thermistors and lasers. The semiconductors have made possible the advent of integrated circuitarythat has completely revolutionized the electronics and computer industries.

8. **Biomaterials:** these materials are employed in components implanted into the human body for replacement of diseased or damaged body parts. Biomaterials should not produce toxic substances and must be compatible with body tissues, i.e. should not cause adverse biological reactions. We may note all of the above materials, i.e. metals, ceramics, polymers, composites, semiconductors, etc. may be used as biomaterials. Some of the biomaterials are utilized in artificial hip replacements.
9. **Advanced materials:** these are new engineering materials which exhibit high strength, great hardness, and superior thermal, electrical, optical and chemical properties. Advanced materials have dramatically altered communication technologies, reshaped data analysis, restructured medical devices, advanced space travel and transformed industrial production process. These materials are often synthesized from the products of conventional commodity materials and often possess following characteristics:

- are created for specific purposes;
- are highly processed and possess a high value-to weight ratio;
- are developed and replaced with high frequency;
- are frequently combined into new composites.

Nowadays, there is considerable interest in making advanced materials that are usually graded by chemical composition, density or coefficient of thermal expansion of material or based on micro-structural features, *e.g.* a particular arrangement of second-phase particles or fibres in a matrix. Such materials are referred as *functionally graded materials.* Instead of having a step function, one may strive to achieve a gradual change. Such gradual change will reduce the chances of mechanical and thermal stresses, generally present otherwise. We may note that the concept of a functionally graded material is applicable to any material metal, polymer or ceramic. A lot of research work is going on these materials.

10. **Smart Materials:** Smart or intelligent materials form a group of new and state of art materials now being developed that will have a significant influence on many of present-day technologies. The adjective ‘smart’ implies that these materials are able to sense changes in their environments and then respond to these changes in predetermined manners that are also found in living organisms. In addition, the concept of smart materials is being extended to rather sophisticated systems that consist of both smart and traditional

materials. The field of smart materials attempts to combine the *sensor,* that detects an input signal, *actuator*, that performs a responsive and adaptive function and the control circuit or as one integrated unit. Acutators may be called upon to change shape, position, natural frequency, or mechanical characteristics in response to changes in temperature, electric fields, and or magnetic fields. Usually, four types of materials are commonly used for actuators: *shape memory alloys, piezo-electric ceramics, magnetostrictive materials,* and *electrorheological or magnetorheological fluids*. Shape memory alloys are metals that, after having been deformed, revert back to their original shapes when temperature is changed. Piezoelectric ceramics expand and contract in response to an applied electric field, conversely these materials also generate an electric field when their dimensions are altered. The behavior of magnetostrictive materials is analogous to that of the piezoelectric ceramic materials, except that they are responsive to magnetic fields. Also, electrorheological and magnetorheological fluids are liquids that experience dramatic changes in viscosity upon application of electric and magnetic fields, respectively. This group includes also the **Nanomaterials** that are nanostructured defined as solids having microstructural features in the range of 1–100 nm (= (1–100) × 10−9m) in at least in one dimension. These materials have outstanding mechanical and physical properties due to their extremely fine grain size and high grain boundary volume fraction. Usually, the clusters of atoms consisting of typically hundreds to thousands on the nanometer scale are called as nanoclusters. These small group of atoms, in general, go by different names such as nanoparticles, nanocrystals, quantum dots and quantum boxes. Significant work in being carried out in the domain of nanostructured materials and nanotubes since they were found to have potential for high technology engineering applications. Nanostructured materials exhibit properties which are quite different from their bulk properties. These materials contain a controlled morphology with at least one nanoscale dimension. Nanocrystals, nanowires and nanotubes of a large number of inorganic materials have been synthesized and characterized in the last few years. Some of the nanomaterials exhibit properties of potential technological value. This is particularly true for nanostructures of semiconducting materials such as metal chalcogenides and nitrides. The mixing of nanoparticles with polymers to form composite materials has been practiced for decades. Significant progress has been made in various aspects of synthesis of nanostructured materials. The explosion of both academic and industrial interest in these materials over the past decade arises from the remarkable variations in fundamental electrical, optical and magnetic properties that occur as one progresses from an infinitely extended solid to a particle of material consisting of a countable number of atoms. The focus is now shifting from synthesis to manufacture of useful structures and coatings having greater wear and corrosion resistance. Materials produced out of nanoparticles have some special features:

- very high ductility;
- very high hardness ~4 to 5 times more than usual conventional materials;
- transparent ceramics achievable;
- manipulation of color;
- extremely high coercivity magnets;
- developing conducting inks and polymers.

1.8.2 Technology forecast

The debate of how technological development, including new materials, impact on business performance is highly topical. Some authors relating technological innovation are even saying that “In many industries technological innovation is now the most important driver of competitive success[93]”, and “In order to keep a competitive position in the market, firms have to rely on new technologies that have the potential to increase their revenues[94]“. Another line of research, often related to the previous one, is the innovation prediction. Forecasting the evolution of new technologies is of great interest to innovators and R&D managers. Perez argues that “Technological forecasting aims to anticipate the direction and speed of change in technological fiends, enabling the early detection of revolutionary technologies[95]” and again Byungun et all. “technological forecasting is an unavoidable process for devising successful policies that can meet both public and private needs.[96]”The explanation of firms’ innovation success has a long research

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[93] Barczak G., Griffin A., Kahn K. B. “Trends and drivers of success in npd practices: results of the 2003 pdma best practices study” Journal of Product Innovation Management 26, (2009);

[94] Taşkin H., Adali M.R., Ersin E. “Technological intelligence and competitive strategies: an application study with fuzzy logic” Journal of Intelligent Manufacturing, (2004)

[95] Perez C. “Technology change and opportunities for development as a moving target” UNCTAD, (1999)

[96] Byungun Y., Sungjoo L. “Applicability of patent information in technological forecasting: a sector-specific approach” Journal of Intellectual Property Rights 17, (2012)

tradition and has lately received renewed attention due to increasing innovation costs, decreasing innovation times and increasing technology complexity[97].

In recent years, researchers have explored many approaches to technological forecasting, some of which are briefly summarized in the following table:

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[97] Ritter T., Gemünden H. G. "The impact of a company's business strategy on its technological competence, network competence and innovation success" Journal of Business Research 57, (2004).

Fig. 1.1 Some papers on approaches to technological forecasting

Author(s) (Year)	Approach(es)
H. Small et all. (1974)	Co-citationanalysis
P. Young (1993) N. Meade et all (1998)	Diffusion of new technologies and evaluated application of the technological growth curves for several time series data sets of various technologies
R. J. Watts et all. (1997)	Bibliometrics with trend forecasting
H. Ernst (1997)	Patent data to assess diffusion of CNC technology in machine tool industry
A. D. Lemos (1998)	Structural models: scenarios and technological vigilance.
P. A. Geroski (2000)	Epidemic model for technology adoption similar to the spread of epidemic diseases
J. P. Martino (2003)	Comprehensive review of contemporary methods: environmental scanning, Delphi models, extrapolation and probabilistic forecasting
M. Brinn et all. (2003)	Forward citation
A. L. Porter (2004)	Technology futures analysis: primary source of data for technology evolution studies
S. D. Massini (2004)	Growth behavior tends to follow the shape of the letter ”S” and generally is referred to as “S-curve”
Jaffe et all. (2005)	Patent data to identify and assess knowledge spillovers
T. Daim et all. (2006)	Bibliometrics are integrated with scenario planning, growth curves and analogistic reasoning. Introduce papermetrics.
M. H. Fallah et all. (2006)	Use diffusion models to forecast saturation levels for cell phones
A. C. Marco (2007)	Dynamics of patent citation and points to the heterogenity of patent citation data
K. Hoisl (2007)	Effect of mobility on inventor productivity
A. B. Renzi et all (2015)	Delphi and consensusmethod
Albert et all (2015)	Blog analysis and rolling cluster algorithms

1.8.3 Patent analysis in forecasting new materials

It has become the norm for successful companies to have consistently to develop new products if they are to gain or maintain a competitive edge in such a turbulent environment. The historical patterns of patent applications often indicate the trends of growth in a technology area. In engineering management, patent analysis has long been regarded as a crucial method for strategic decision-making and is being increasingly highlighted in high technology management as innovation processes become more complex and the cycle of innovation becomes shorter. From a macro perspective, patent statistics are adopted to evaluate innovation processes and provide indicators of national technological capacity[98]. Meanwhile, from a micro perspective, considerable studies analyze patent information to assess the effectiveness of R&D activities and identify potential research areas[99]. Patent analysis has also served as a valuable reference for priority-setting in R&D investment by investigating financial efficiency[100]. Many firms have come to consider patents as a source of competitive power and emphasize patent acquisition as a part of their business strategies.[101]

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[98] Ernst H. “Patent applications and subsequent changes of performance: evidence from time-series cross-section analyses on the firm level” Research Policy 30, (2001);

[99] Jeon J., Lee C., Park Y. “How to use patent information to search potential technology partners in open innovation” Journal of Intellectual Property Rights 16, (2011)

[100] Hirschy M., Richardson V. “Valuation effects of patent quality: a comparison for Japanese and US firms” Pacific-basin Finance Journal 9, (2001).

[101] Tsuji Y. S. “Organizational behavior in the R&D process based on patent analysis: strategic R&D management in a Japanese electronics firm” Technovation 22, (2002).

Demonstration of the great interest in predicting new materials success based on patent analysis, below are some recent works:

Fig. 1.2 Some recent papers on predicting new materials success

Author(s) (Year)	Material	Journal	Author(s) (Year)	Material	Journal
A. Stephan et all (2017)	Alloy	Research Policy	C. W. Hsu et all (2016)	Biomaterial	International Journal of Hydrogen Energy
D. H. Milanez et all (2017)	Alloy	Journal of Alloys and Compounds	A. Starr et all (2016)	Biomaterial	Pharmaceuticalpatentanalyst
M. Montazerian et all (2017)	Ceramic	Journal of Materials Science	M. R. Salvador et all (2016)	Biomaterial	Journal of Intelligence Studies in Business
L. Slade et all (2017)	Glass	Critical Reviews in Food Science and Nutrition	G. G. Gnesin (2016)	Ceramic	Powder Metallurgy and Metal Ceramics
D. H. Milanez et all (2017)	Glass	Journal of Alloys and Compounds	M. L. F. Nascimento (2016)	Ceramic	Recent Patents on Materials Science
B. Zhang et all (2017)	Metal	Expert Opinion on Therapeutic Patents	M. UI - Islam et all (2016)	Composite	RecentPatents on Nanotechnology
M. U. Khobragade et all (2017)	Metal	RecentPatents on Engineering	W. Qu et all (2016)	Composite	Materials China
D. H. Milanez et all (2017)	Metal	Journal of Alloys and Compounds	H. Li et all (2016)	Composite	MATEC Web of Conference
L. Slade et all (2017)	Polymer	Critical Reviews in Food Science and Nutrition	A. E. Kolosov (2016)	Composite	Chemical and PetroleumEngineering
R. Alderliesten (2017)	Polymer	Solid Mechanics and its Applications	I. P. Kaminskii et all (2016)	Composite	KeyEngineeringMaterials
R. B. Siebert (2017)	Semiconductor	International Journal of Industrial Organization	M. L. F. Nascimento et all (2016)	Glass	World Patent Information
S. Morricone et all (2017)	Semiconductor	Research Policy	D.D. Mahale et all (2016)	Glass	Desalination and Water Treatment
C. C. Wang et all (2017)	Semiconductor	Technological Forecasting and Social Change	M. L. F. Nascimento (2016)	Glass	Recent Innovations in Chemical Engineering
C.C. Wang et all (2017)	Semiconductor	Portland Int. Conf. on Manag. of Engin. and Techn.	M. L. F. Nascimento (2016)	Glass	Recent Patents on Materials Science
L. F. Chanchetti et all (2016)	Alloy	International Journal of Hydrogen Energy	L. Li et all (2016)	Metal	Expert Opinion on Therapeutic Patents
N. Li et all (2016)	Alloy	international Conference on Industrial Engineering	S. C. Yenisetti et all (2016)	Metal	Recent Patents on CNS Drug Discovery
J. H. Yang et all (20116)	Alloy	Chinese Journal of Tissue Engineering Research	H. Heli et all (2016)	Metal	RecentPatents on Nanotechnology

Author(s) (Year)	Material	Journal	Author(s) (Year)	Material	Journal
D. J. Roth (2016)	Metal	TMS Light Metals	Y. Zheng et all (2015)	Alloy	Materials China
R. Bawa (2016)	Nanomaterial	Handbook of Clinical Nanomedicine	S. Rama Mohan (2015)	Biomaterial	International Journal of Hydrogen Energy
I. Ojima et all (2016)	Nanomaterial	Expert Opinion on Therapeutic Patents	C. Gargiulo et all (2015)	Biomaterial	Recent Patents on Regenerative Medicine
D. Elvers et all (2016)	Polymer	PolymerReviews	C. W. Hsu et all (2015)	Biomaterial	Biomass and Bioenergy
D. Heinisch et all (2016)	Polymer	Economics of Innovation and New Technology	F. Michelino et all (2015)	Biomaterial	Conference - Innovation Vision 2020
C. Soica et all (2016)	Polymer	RecentPatents on Nanotechnology	F. Michelino et all (2015)	Biomaterial	Journal of Technology Management and Innovation
L. C. du Toit et all (2016)	Polymer	Expert Opinion on Therapeutic Patents	C. Yue et all (2015)	Ceramic	Recent Patents on Materials Science
Z. Zhang et all (2016)	Semiconductor	Journal of Nanoscience and Nanoteechnology	Y. Peng et all (2015)	Composite	Recent Patents on Materials Science
K. S. Siow et all (2016)	Semiconductor	Proceedings of the IEEE/CPMT	Y. Sun et all (2015)	Composite	Transactions on Dielectrics and Electrical Insulation
W. Seo et all (2016)	Semiconductor	Intern. Conf. on Dependable, Autonomic and Secure Computing	G. P. Knowles et all (2015)	Composite	AdvancesMaterials - TechConnect Briefs
Q. Liu et all (2016)	Semiconductor	Jiqiren/Robot	A. Kumar et all (2015)	Glass	RecntPatents on Biotechnology
J. H. Lau (2016)	Semiconductor	China Semic. Techn. Intern. Conf. 2016	A. Sarkar et all (2015)	Metal	RecentPatents on Biotechnology
M. Kim (2016)	Semiconductor	Strategic Management Journal	A. L. Hicks et all (2015)	Nanomaterial	Environmental Science and Technology
J. Hohberger (2016)	Semiconductor	Technological Forecasting and Social Change	C. D. Kane et all (2015)	Nanomaterial	Expert Opinion on Therapeutic Patents
A. B. Kahng et all (2016)	Semiconductor	IEEE/ACM Intern. Conf. on Computer	D. Shcharbin et all (2015)	Nanomaterial	Expert Opinion on Therapeutic Patents
D. Zivkovic et all (2015)	Alloy	RecentPatents on Nanotechnology	B. Mukherjee et all (2015)	Nanomaterial	CurrentPharmaceutical Design
D. Sharrott et all (2015)	Alloy	NanotechnologyLaw and Business	A. M. Elwerfalli et all (2015)	Polymer	CurrentDrug Delivery
			R. Arvidsson et all (2014)	Composite	Environmental Science and Technology

CHAPTER TWO

PATENT ANALYSIS IN FORECASTING NEW MATERIALS SUCCESS

2.1 Introduction

In technology investment assessments come up with a variety of business factors and functions, such as marketing, human resources, location, and so on. To anticipate the benefits of developing a new technology is very interesting for businesses, but, as already mentioned in the previous chapter, investment on innovation is needed to maintain business competitiveness but, on the other hand, brings with it many risks.

In the process of predicting technological success, economic literature has investigated several elements that may be helpful in evaluation processes, and provide a good basis for assessing its future development, such as: technology life cycle under consideration, the potential diffusion and the technological scope. Patents, in addition to being an excellent indicator of innovation, can be useful in calculating the technology life cycle, potential diffusion, and application fields of a technology. In the present paper, we will use these four variables to predict the technological success of 10 types of new materials and thus evaluate their attractiveness in terms of possible investments.

2.2 Literature review

In the economic literature there are many works dealing with promising technologies, however, it is not easy to provide a single definition. Cozzens et al.[102] examined the literature and formalized four main concepts related to the definition of emerging technologies: (1) rapid recent growth, (2) transition to something new, (3) untapped market or economic potential and (4) an increase base in science. Later, similarly, Rotolo et al.[103] defined four aspects of emerging technologies: (1) radical novelty, (2) relatively rapid growth, (3) consistency and (4) uncertainty and ambiguity. Based on these studies, we can conclude that promising technologies are of recent invention, with uncertain development but with high possibilities of future technological development and impact on the market[104].

The main approaches to evaluate promising technologies can be classified into two types: 1) qualitative assessment carried out by the experts and 2) quantitative evaluation based on data. In addition, various approaches have been adopted to identify and prioritize promising technologies, such as the analytical hierarchy

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[102] Cozzens S., Gatchair S., Kang J., Kim K.S., Lee H.J., Ordóñez G., Porter A. "Emerging technologies: quantitative identification and measurement." Technology Analysis & Strategic Management 22, (2010)

[103] Rotolo D., Hicks D., Martin B.R. "What is an emerging technology?" Research Policy 44, (2015)

[104] Noh H., Song Y.K., Lee S. "Identifying emerging core technologies for the future: case study of patents published by leading telecommunication organizations." Telecommunication Policy 40 (2016)

process (AHP)[105], Delphi[106], clustering[107], roadmaps[108] and forecasts[109]. However, with the increasing complexity of the technology and the extension of technological applications, the validity of the qualitative assessment by the experts could exclude some relevant elements. To complete expert analytical process, some quantitative approaches have been developed. Among these, one of the most commonly adopted is patent analysis. Patent documents contain semi-structured bibliographic information as well as descriptive information detailing the technological components, principles and potential benefits. Patent data is easy to evaluate, is open to the public and collects information from several decades. Thanks to these distinctive characteristics, patent data are considered the main sources of knowledge for innovation studies[110].

Patent data provide objective information that helps to understand new technologies in different aspects: from the assessment of technological levels to

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[105] Lee S., Kim W., Kim Y.M., Lee H.Y., Oh K.J. "The prioritization and verification of IT emerging technologies using an analytic hierarchy process and cluster analysis" Technological Forecasting and Social Change 87, (2014)

[106] Bañuls V.A., Salmeron J.L. "Foresighting key areas in the information technology industry." Technovation 28, (2008)

[107] Song M.J., Lee J.G., Park J.M., Lee S. "Triggering navigators for innovative system design: The case of lab-on-a-chip technology." Expert Systems with Applications 39, (2012)

[108] Fleischer T., Decker M., Fiedeler U. "Assessing emerging technologies-methodological challenges and the case of nanotechnologies." Technological Forecasting and Social Change 72, (2005)

[109] Bierwisch A., Kayser V., Shala E. "Emerging technologies in civil security—a scenario-based analysis." Technological Forecasting and Social Change 101, (2015)

[110] Kim J., Lee S. "Patent databases for innovation studies: a comparative analysis of USPTO, EPO, JPO and KIPO." Technological Forecasting and Social Change 92, (2015)

the study of R & D trends[111]. This information have also been used to identify promising technologies and to take further advantage of new business opportunities. For example, they were applied to discover vacant technologies through patent-defined technologies[112], evaluate promising technologies using the analysis of citations of patent[113], or examine the flows of technological knowledge and the possible technological convergence[114].

The main approaches in patent assessment can be divided into two macro-categories: the first that defines a technology as a collection of patents, while the second interprets a single patent as a theoretical focal point of analysis[115].

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[111] Trappey A.J., Trappey C.V., Wu C.Y., Lin C.W. "A patent quality analysis for innovative technology and product development." Advanced Engineering Informatics 26, (2012); Kim J., Lee S. "Patent databases for innovation studies: a comparative analysis of USPTO, EPO, JPO and KIPO." Technological Forecasting and Social Change 92, (2015); Jin G., Jeong Y., Yoon B. "Technology-driven roadmaps for identifying new product/market opportunities: use of text mining and quality function deployment." Advanced Engineering Informatics 29, (2015)

[112] Lee S., Yoon B., Park Y. "An approach to discovering new technology opportunities: keyword-based patent map approach." Technovation 29, (2009); Jun S., Park S., Jang D. "Technology forecasting using matrix map and patent clustering." Industrial Management & Data Systems 112, (2012); Choi S., Jun S. "Vacant technology forecasting using new Bayesian patent clustering." Technology Analysis & Strategic Management 26, (2014)

[113] Breitzman A., Thomas P. "The emerging clusters model: a tool for identifying emerging technologies across multiple patent systems." Research Policy 44, (2015); Shen, Y., Chang S., Lin G., Yu H. "A hybrid selection model for emerging technology." Technological Forecasting and Social Change 77, (2010)

[114] Geum Y., Kim C., Lee S., Kim M. "Technological convergence of IT and BT: evidence from patent analysis." ETRI J., (2012); Caviggioli F. "Technology fusion: identification and analysis of the drivers of technology convergence using patent data." Technovation, (2016)

[115] Song K., Kim K., Lee S. "Identifying promising technologies using patents: A retrospective feature analysis and a prospective needs analysis on outlier patents." Technological Forecasting & Social Change 128, (2018)

The first approach, in turn, can be divided into two other sub-categories. One of them defines the technologies by assigning patents to each one of them, then analyzing trends, as a sequence of technology definition and patent assessment. An example of this methodology is when used international patent classification (IPC) codes to assign relevant information technology (IT) and biotechnology (BT) patents in their studies to investigate the convergent IT and BT areas[116]. Thus, by defining an IPC code as a technology, they analyzed the characteristics of the patents in each of the IPC codes to identify emerging technologies.

The remaining sub-category first extracts the valuable patents and then defines the technologies by grouping them according to their similarity of content. In this case the patents evaluation sequence and the technology definition are carried out. For example, Noh et al.[117] selected some patents based on citation information and then defined the technological areas by grouping the patents into groups by means of bibliographic coupling.

Turning to the second category, the purpose of these analyzes is focused on the identification of a valuable patent rather than on a valid technological field. For example, Lee et al.[118] developed an algorithm to predict the expected citation

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[116] Geum Y., Kim C., Lee S., Kim M. "Technological convergence of IT and BT: evidence from patent analysis." ETRI J., (2012)

[117] Noh H., Song Y.K., Lee S. "Identifying emerging core technologies for the future: case study of patents published by leading telecommunication organizations." Telecommunications Policy, (2016)

[118] Lee C., Kim J., Kwon O., Woo H. "Stochastic technology life cycle analysis using multiple patent indicators." Technological Forecasting and Social Change 106, (2016)

frequencies of the patents and used the results to evaluate the patents. Jeong et al.[119] tried to identify the emerging technologies from outlier patents, which were not included in any of the main technological areas and therefore were new with respect to previous technologies. These approaches can be applied effectively to patent assessment.

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[119] Jeong Y., Lee K., Yoon B., Phaal R. "Development of a patent roadmap through the generative topographic mapping and bass diffusion model." Journal of Engineering and Technology Management 38, (2015)

2.3 Sample

The data was collected from the database Amadeus (Bureau Van Dijk) updated on20 July 2017. In the first phase, the patent titles were selected using as research queries "kind of material" and the word "material". For example, for semiconductor patents, have been included in patents title criteria the following logic operators “Semiconductor” and “material”. This procedure has been repeated for the following types of material: Advanced materials, Alloys, Biomaterials, Ceramics, Composites, Gasses, Metals, Nanomaterials, Polymers, Semiconductors. The dataset consists of two parts: a first part composed of all patents registered from 1890 until 1999, while the second part, aimed at verifying the results, is obtained by adding to the first part the patents registered from 2000 to 2010. At the beginning of the study, the entire dataset was composed as follows:

Tab. 2.1 Whole sample composition

Material	Number of patents	%
Advanced materials	44	0,04%
Alloy	7.607	7,00%
Biomaterials	2.415	2,22%
Ceramics	9.220	8,49%
Composites	70.039	64,48%
Glasses	1.720	1,58%
Metals	5.302	4,88%
Nanomaterial	1.121	1,03%
Polymers	5.326	4,90%
Semiconductors	5.835	5,37%
Total	108.629	

The dataset shows a different weight in terms of attendance within the same categories. The categories with more patents are Composites (64.48%), Ceramics (8.49%) and Alloy (7%), while the least represented categories are Advanced materials (0.04%) and Nanomaterials (1,03%).

In order to improve the reliability of the data processed, only the patents actually registered were selected and the results are summarized in the table below:

Tab. 2.2 Composition of only granted patents sample

Material	Number of patents	%
Advanced materials	7	0,03%
Alloys	1.110	5,17%
Biomaterials	418	1,95%
Ceramics	2.893	13,48%
Composites	12.837	59,83%
Glasses	378	1,76%
Matals	1.019	4,75%
Nanomaterials	61	0,28%
Polymers	1.162	5,42%
Semiconductors	1.569	7,31%
Total	21.454	

The work consists of two parts: in the first part all data will be analyzed until 1999, imagining to put the time of evaluation of the different materials at the beginning of 2000; in the second part, we will repeat the whole process with complete data for 2010 so that we can verify the veracity of the results obtained in the first phase and therefore of the methodology performed.

Tab. 2.3 composition of only granted patents sample until 2000

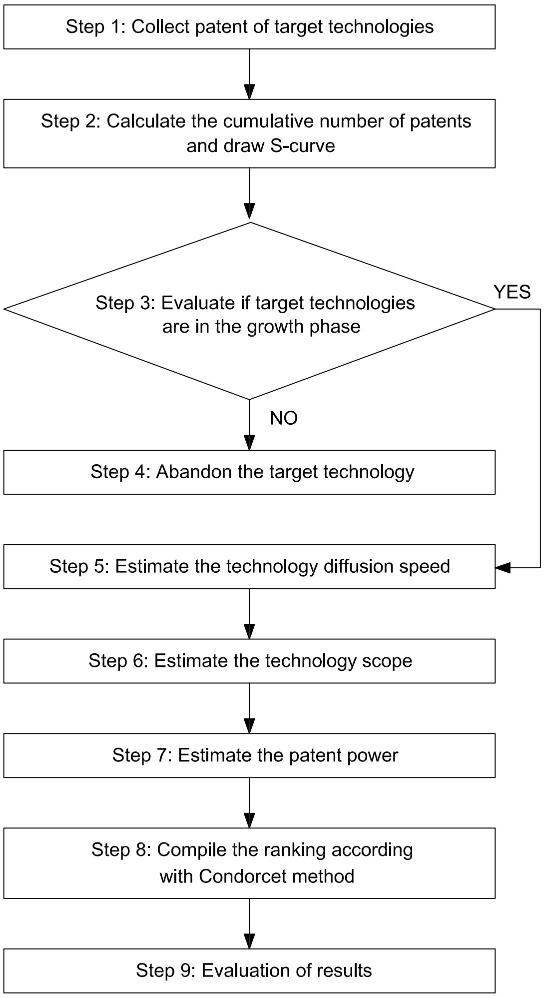
Material	Number of patents	
Advanced materials	6	0,06%
Alloys	504	4,98%
Biomaterials	101	1,00%
Ceramics	1.990	19,65%
Composites	5.431	53,62%
Glasses	177	1,75%
Metals	404	3,99%
Nanomaterials	-	0,00%
Polymers	582	5,75%
Semiconductors	934	9,22%
Total	10.129	

The number of patents has significantly decreased of 87,175 units (approximately 80%), leaving the ranking between classes almost unaltered.

2.4 Proposed method

As already mentioned, the proposed method is aimed to identify an order of preference for investments between new technologies. Some indicators are used during the proceedings to evaluate technological success and systematically prioritize available investment opportunities over their sustainability in the future. The proposed method consists of nine steps, as shown in the following figure:

Fig. 2.1 Proposed method



In Phase 1, data relating to the target technologies patent is collected.

In the next step, the S curve is constructed cumulating patents registered in previous years. The trend of the curve obtained indicates the attractiveness and the trend of the technology over time.

In the third step, it is necessary to evaluate whether target technology is in the growth phase. At this point, if the technologies are not in the growth phase, the process goes to step 4, which involves discarding the target technology, otherwise it goes to step 5. At this stage, the calculation of the indices starts and the first is the technology diffusion speed, as indicated in the expression (1).

In step 6, we calculate the first index that measures the technology scope, the expansion potential, which corresponds to the total number of IPC codes registered in the target technology patents, as indicated in the expression (2).

In the next phase, the other technology scope index is calculated, with the aim of measuring the patent power, as indicated in the expression (3). The last two phases described above give an indirect measure of target technology market potential. All of the variables just described are illustrated in the following paragraph.

Once the data is collected and the respective indexes are obtained, in step 8 the ranking is listed according to the Condorcet method.

In the last phase, the results are evaluated.

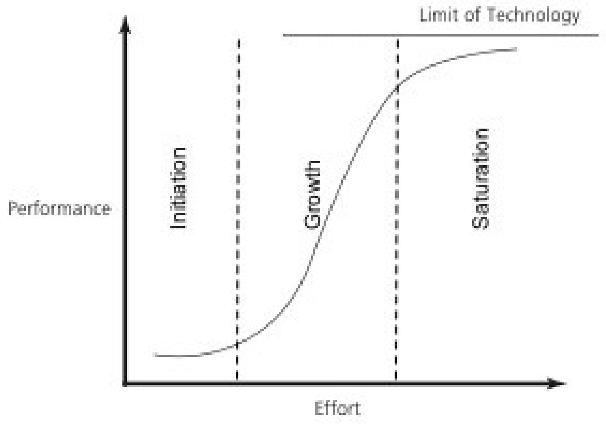
2.5 Variable definitions

Starting point of this work is that information in technology forecasting should be easily accessible, otherwise the whole process would be difficult to implement and therefore of limited usefulness. Over the years, the literature has developed several indicators of technological forecasts, and among them, patents are among the most frequent, because they are easily and freely accessible. By using patents, different types of indicators can be developed, such as patent citations, age, technology classification (IPCs) and others. Several authors have pointed out that the current phase of the *technology lifecycle* is of particular importance in assessing future investment decisions, and one of the most effective tools to evaluate it is the S curve, which has already been discussed in the previous chapter. Another aspect to consider when evaluating investment projects is to assess the extent to which technological innovation is a new basis for developing others; in order to do so, it is necessary to estimate the *rate of diffusion*. If the speed of development of an innovation is high, this could mean that technology may have a higher market potential and may therefore affect markets other than the origin market. It is therefore evident that the technological scope is another variable of interest in terms of innovation value. In summary, it can be stated that in evaluating a technological investment it is desirable that it should be in the growth phase, with respect to its technological life cycle, with a high diffusion potential and a wide range of reference markets (technological scope).

2.5.1 Technology life cycle

One of the variables that should always be aware of in technological investments is their current life cycle. Several authors identify at least three phases of the technological life cycle, that is, initiation, growth and saturation. These steps are illustrated in Figure 1.

Fig. 2.2 S-curve of technology life cycle



During the state of initiation, technology is still new on the market and there is a considerable chance that technology can be replaced with another more recent in the saturation phase. As seen in the previous chapter, investments can also be made at the end of the initial phase and at the beginning of the saturation phase, but you have to remind that the risk profiles are different. The approach proposed in this work, which refers to the work of Altuntas et al.[120], assumes that investments are advantageous if they are made during the growth phase. In this regard, the cumulative number of patents is used to identify the current phase in the life cycle of target technologies.

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[120] Altuntas S., Dereli T., kusiak A."Forecasting technology success based on patent data" Technological Forecasting & Social Change 96, (2015)

2.5.2 Technology diffusion speed

As already mentioned in the previous chapter, technology can spread and therefore be used by several companies. Patent citation analysis can be used as a way to evaluate the speed of diffusion of technology innovations. If a patent is cited by subsequent patents, this implies that the cited patent is diffused, applied and valuable[121]. Investment in technology that has a high potential for diffusion can lead to a higher market potential. In this study, the average number of citing patent is used as a proxy for the technology diffusion speed (see expression 1). For more details on measuring the diffusion of patent technology, refer to Altuntas et al. and Huang and Wang[122].

$$Technology\ diffusion\ speed = \frac{Total\ number\ of\ forward\ citations}{Total\ patent\ considered\ for\ diffusion} \quad \textbf{(1)}$$

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[121] Chang S.B., Lai K.K., Chang S.M. ”Exploring technology diffusion and classification of business methods: using the patent citation network” Technology Forecasting and Social Change, 76, (2009)

[122] Huang L., Wang N. “Status and prospects of technology diffusion research based on patent information,” Proceedings of the Sixth International Conference on Management Science and Engineering Management, Islamabad, Pakistan, (2012)

2.5.3 Technology scope

Technology scope criteria mainly assess the impact of a target technology in other economic sectors. If the impact of technology is high, this means that technology is related to many different technologies. This aspect in this paper is evaluated with two different indexes: *patent power* and *potential for expansion*.

In order to estimate these indices, it is necessary to collect the different IPC codes mentioned in the target technology patents. To simplify this procedure, only the first 4 digits of the code are used[123].The potential expansion coincide to the number of IPC classes covered in the granted patents of target technologies.

Expansion potential = IPC classes of target technology **(2)**

A high value of expansion potential suggests that this technology can contribute to further innovations, as it relates to a large number of sectors, since the development of technology leads to the advance of associated technologies. The expansion potential therefore shows the number of additional technologies that target technology refers to.

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[123] Lerner, J. ”The importance of patent scope: an empirical analysis,” RAND Journal of Economics 25 (1994); S. Jun, ”IPC code analysis of patent documents using association rules and maps - patent analysis of database technology” Communications in computer and information science 258, (2011); Gao L., Porter A.L., Wang J., Fang S., Zhang X., Ma T., Wang W., Huang L., “Technology life cycle analysis method based on patent documents,” Technology Forecasting and Social Change 80, (2013)

The second index that estimates the technology scope is the patent power and is defined in expression (3).

$$Patent\ power = \frac{Total\ number\ of\ IPC\ classes\ included\ in\ target\ technology\ target}{Total\ number\ of\ technology\ target\ patents} \quad \textbf{(3)}$$

A high degree of patent power denotes that target technology patents relate to a high number of sectors and therefore has a greater potential for creating new economic sectors. Both potential expansion and patent power are estimated to measure the technology scope and contribute to the final evaluation of target technology.

2.6 Analysis

Phase 1 collects patents relating the main types of materials as identified and described in the previous chapter, which are referred for more in-depth reading. The types of materials studied in this document are: Advanced Materials, Alloys, Biomaterials, Ceramics, Composites, Glasses, Metals, Nanomaterials, Polymers and Semiconductors.

The data was extracted from the database Amadeus (Bureau Van Dijk) updated on20 July 2017. Patents were selected by research queries regarding their title and kept in the dataset only if they possess the granted status. The same procedure was carried out in the EPO database to compare the number of results and since the difference was not very significant, the Amaudeus database was followed for greater simplicity in inventing proprietary companies. The data retrieved are the total number of patents, numbers of citing documents, total number of IPC classes and the number of different IPC classes for each technology. Data on the composition of the dataset and the selection procedure are described in the sample paragraph and the proposed methodology is illustrated in Figure n. 2.1.

Figures from 2.3 to 2.12 illustrate the number of patents granted for each target technology.

Fig. 2.3Numbers of patents for Advanced materials

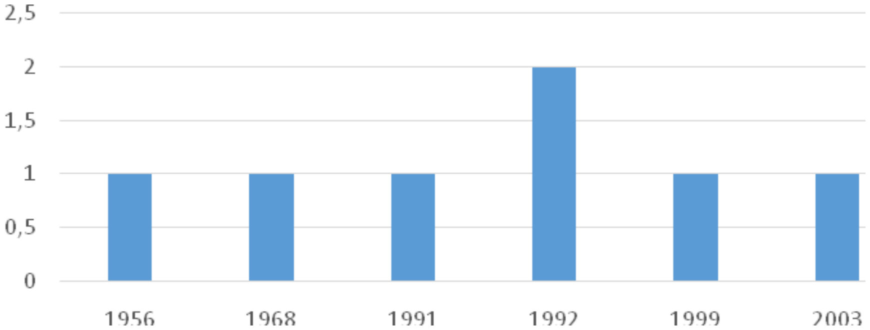


Fig. 2.4Numbers of patents for Alloys

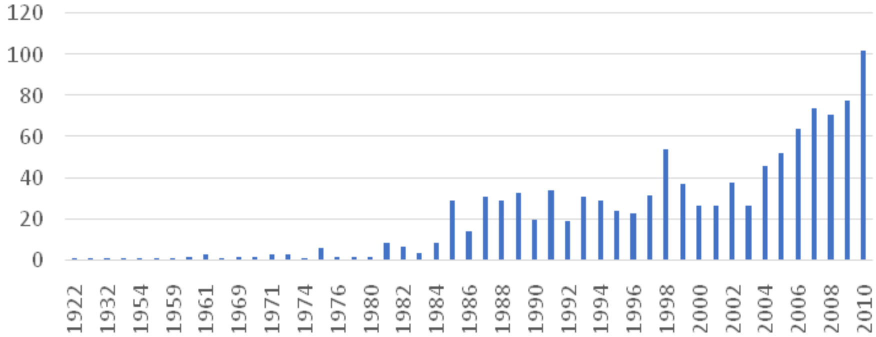


Fig. 2.5 Numbers of patents for Biomaterials

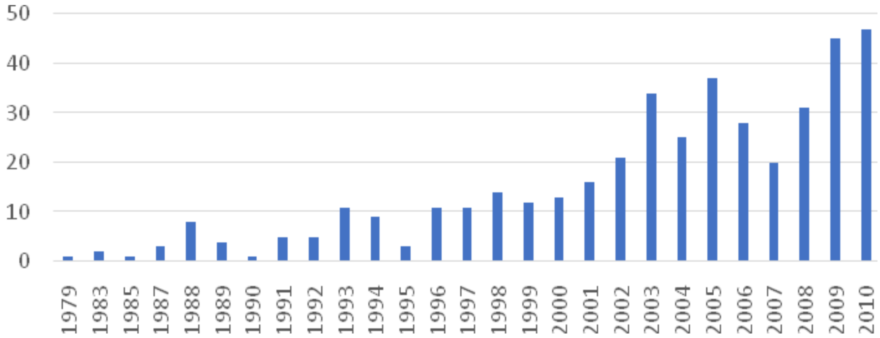


Fig. 2.6 Numbers of patents for Ceramics

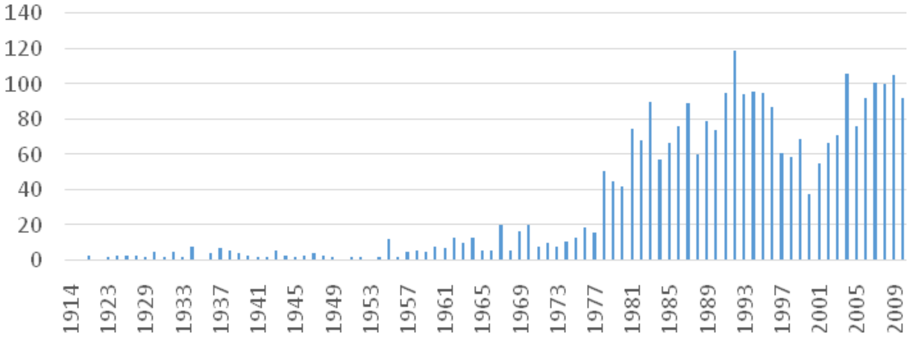


Fig. 2.7 Numbers of patents for Composites

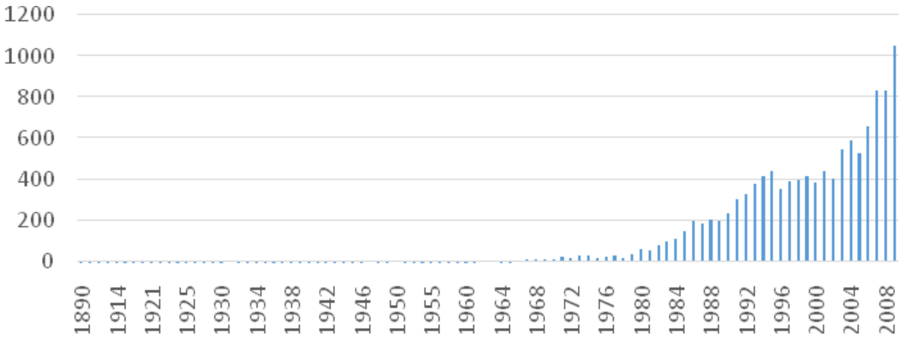


Fig. 2.8 Numbers of patents for Glasses

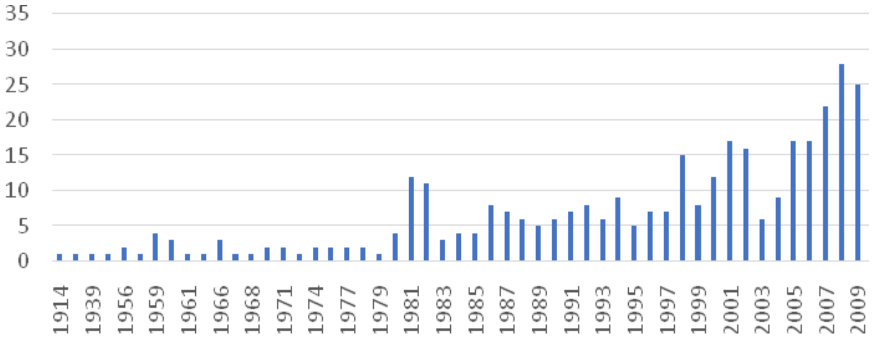


Fig. 2.9 Numbers of patents for Metals

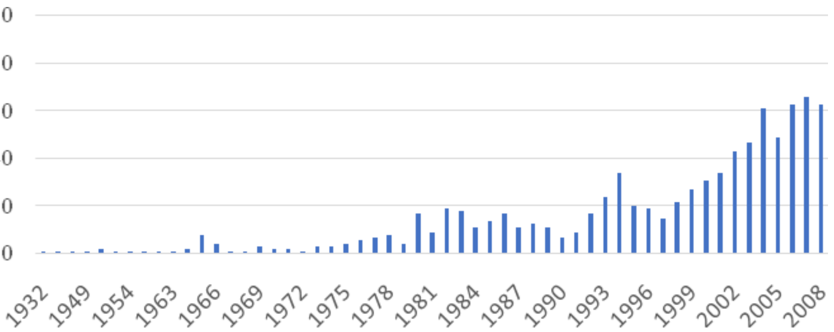


Fig. 2.10 Numbers of patents for Nanomaterials

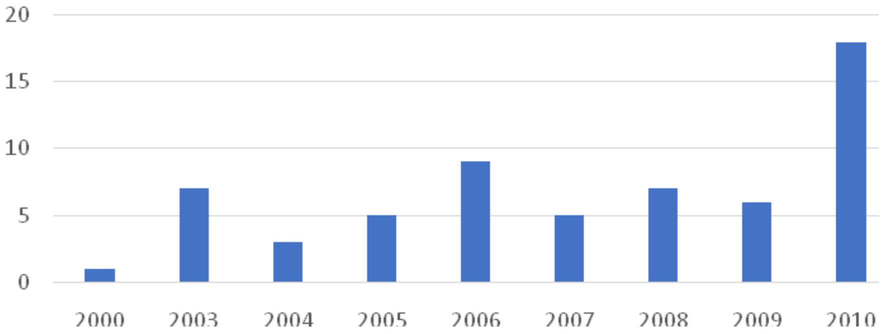


Fig. 2.11 Numbers of patents for Polymers

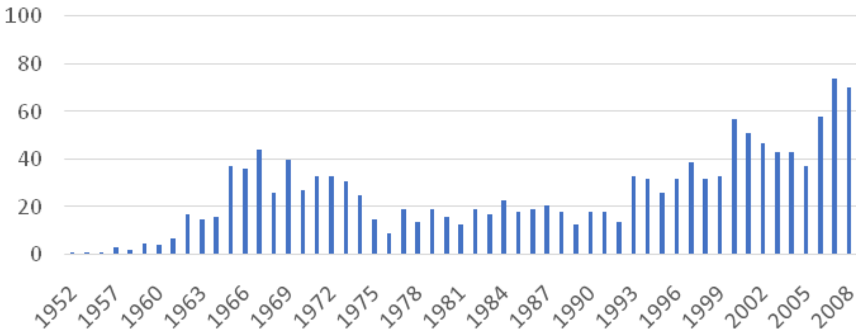
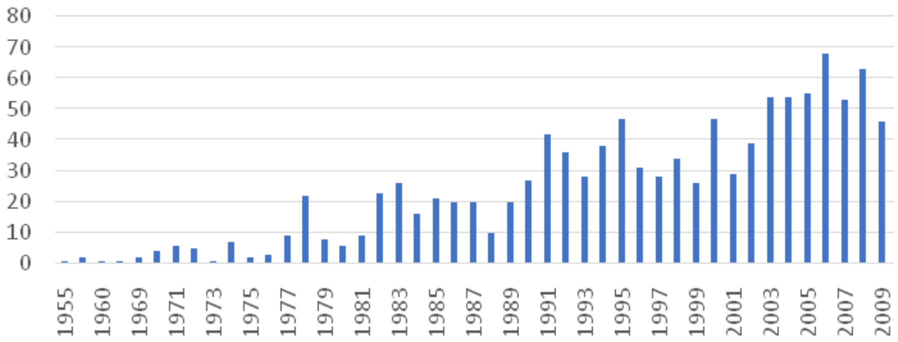


Fig. 2.12 Numbers of patents for Semiconductors



The figures 2.13 and 2.14, for graphic issues, illustrate the S curves for all target technologies studied only from 1980 to 2010. As you can see, these technologies are in the growth phase of their life cycles as their cumulative number of patents have not yet begun to stabilize.

Fig. 2.12 Cumulative numbers of patents 1° group

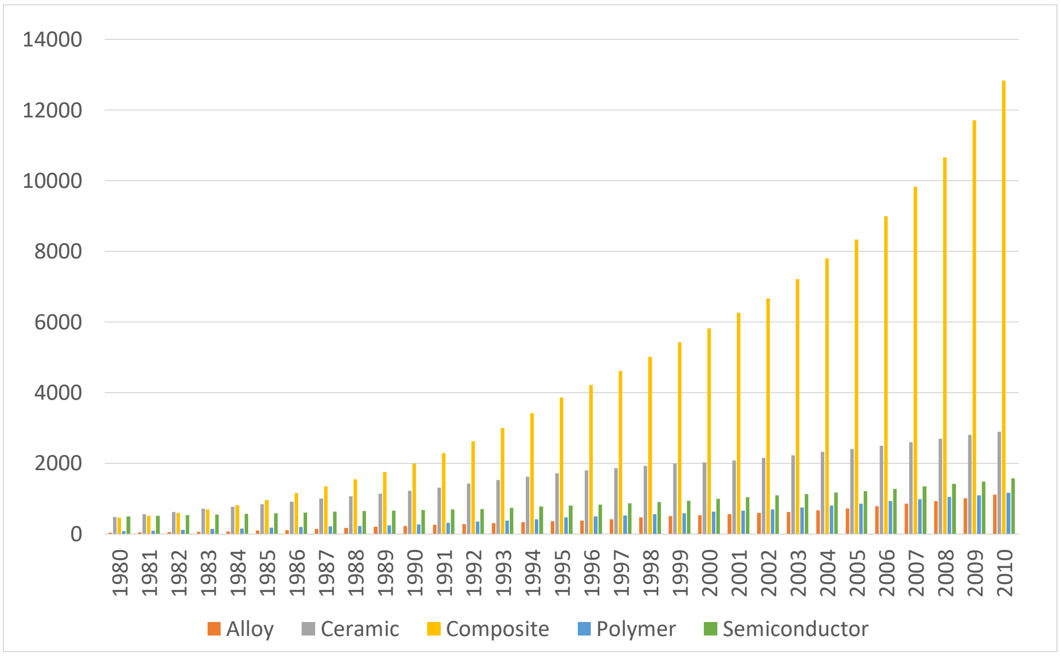
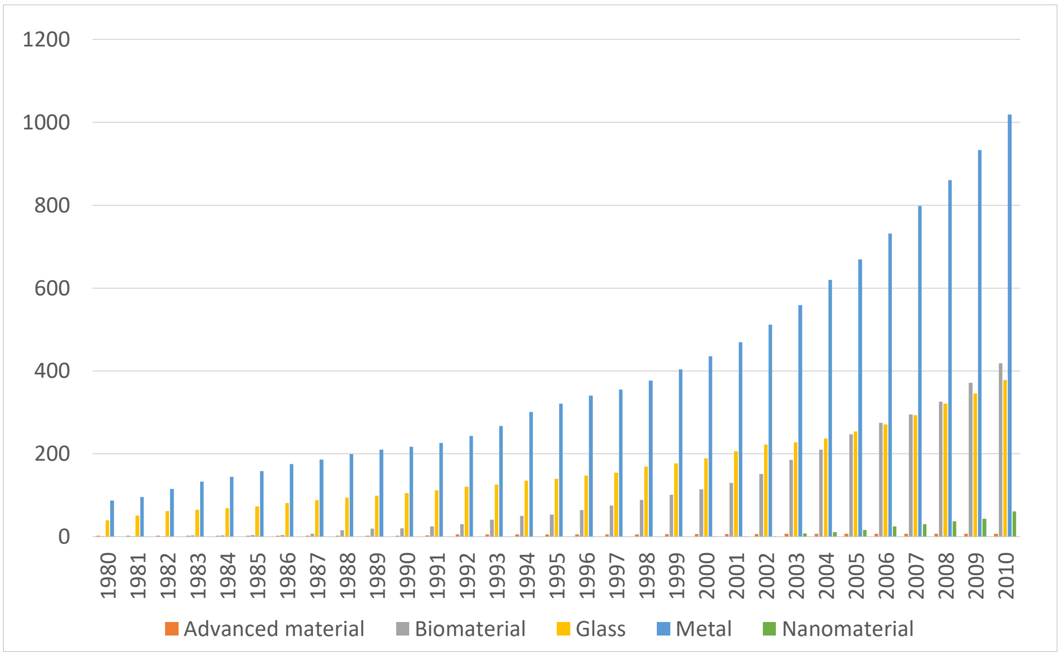


Fig. 2.13 Cumulative numbers of patents 2° group



Figures 2.14 and 2.15 show the levels of citing documents of target technologies from 1980 to 2010.

Fig. 2.14 Citing documents 1°group

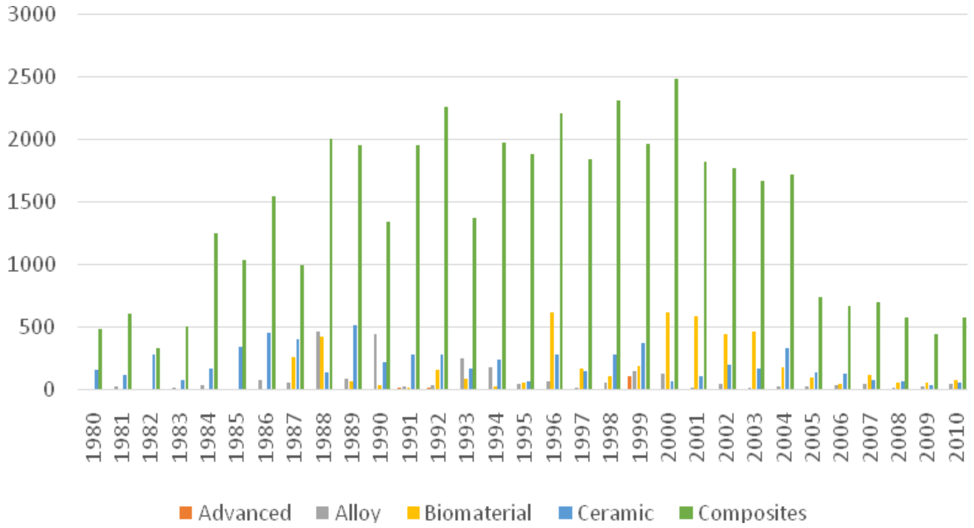
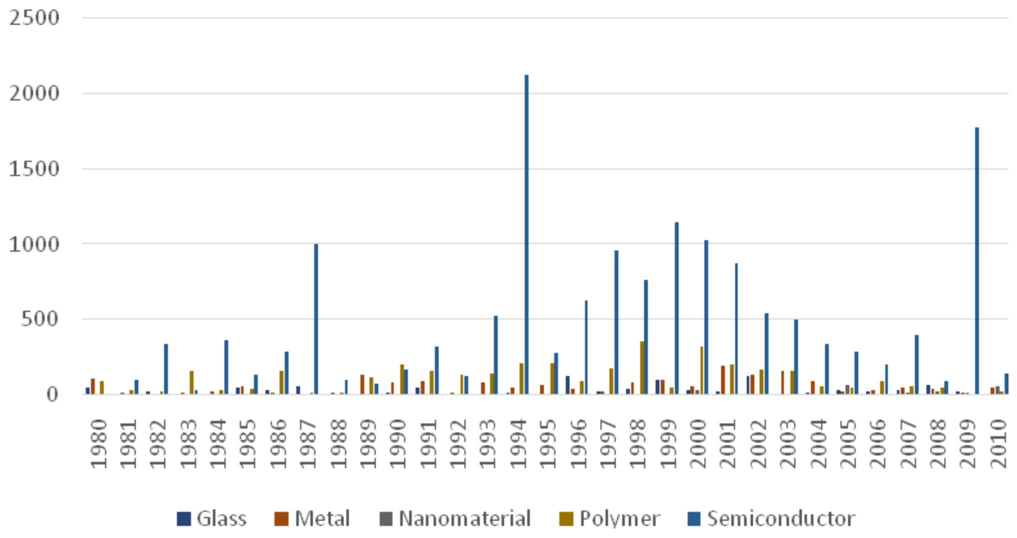


Fig. 2.15 Citing documents 2°group



It has been observed that patents receive the first quotation on average four years after the patent registration[124]. This observation allows us to make two considerations: the first, as already stated above, the dataset is updated to 20 July 2017 and therefore, since the last year being studied in 2010, data should be permanently settled; the second is that the number of patents considered to measure the diffusion speed technology is lower than that used in the patent power estimation. Figures 2.16 and 2.17 show the accumulated levels of citing documents by target technologies and clearly assume the s-curve characters.

Depending on these results, it can be argued that target technologies have not yet reached the saturation phase and can therefore proceed with phase 5.

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[124] C. Gay, C.L. Bas, P. Patel, K. Touach,"The determinants of patent citations: an empirical analysis of French and British patents in the US." Economics of Innovation and New Technology, (2005)

Fig. 2.16 Citing documents 1°group

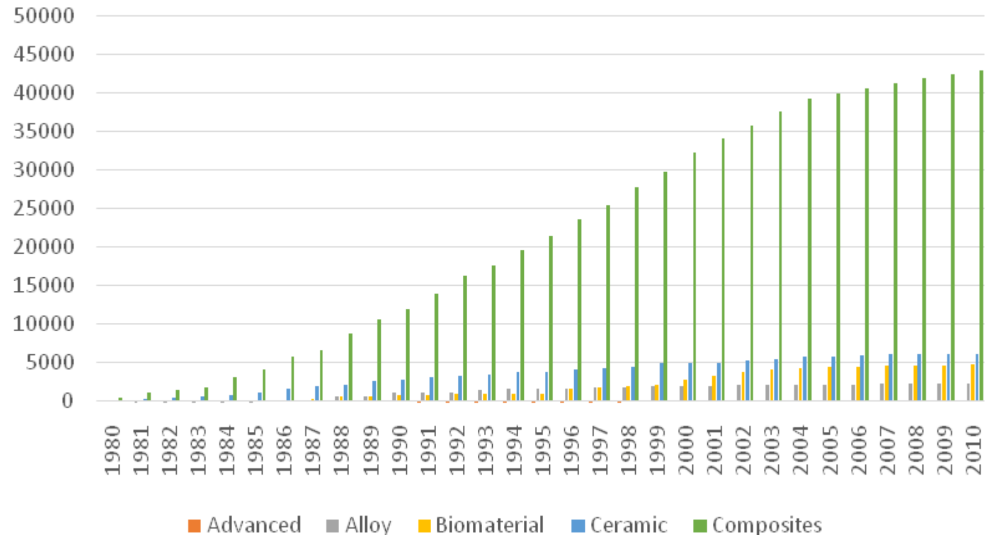

Fig. 2.17 Citing documents 1°group

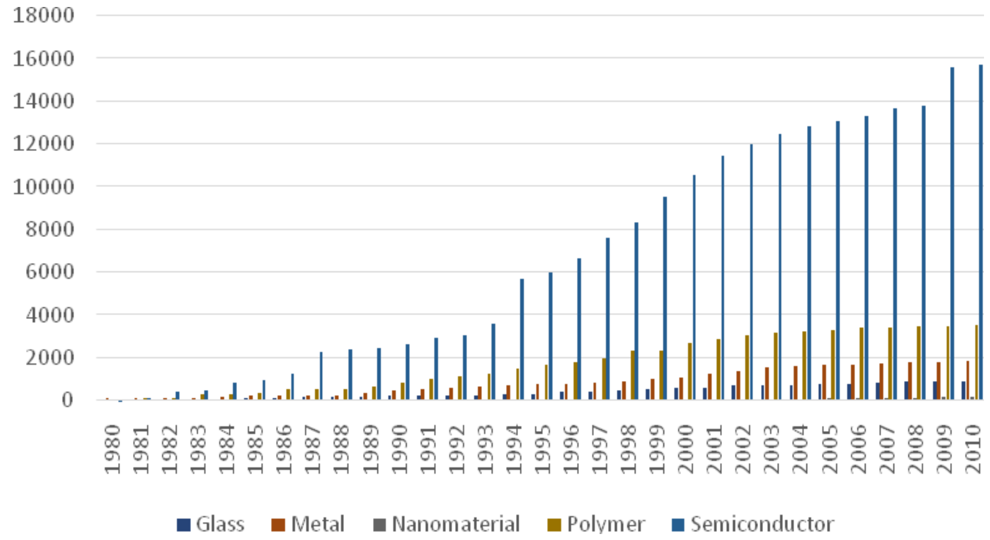

Table 2.4 shows the values of the diffusion speed technology of both periods, listed from the fastest to the slowest. As can be seen the variations in ranking between the two periods affect minimally only those of the second half.

Tab. 2.4 Values of Technology diffusion speed

Material	Technology diffusionspeed			
	2000	Ranking	2010	Ranking
Biomaterial	66,84	1	40,44	1
Advanced material	34,00	2	28,20	2
Semiconductor	26,79	3	26,61	3
Composite	19,47	4	14,23	4
Alloy	18,16	5	13,05	6
Polymer	15,93	6	13,47	5
Glass	12,59	7	10,73	7
Metal	11,47	8	9,00	9
Ceramic	10,94	9	9,94	8
Nanomaterial	-	10	8,57	10

In the estimate of the expansion potential (phase 6), it is necessary to verify the number of IPC classes that the patents refer to. The results of the various target technologies compared are shown in table n 2.5. In this case can be seen a greater reassertion in the ranking compering with the previous variable, however, the target technologies posed in the first 5 positions in the first period reaffirmed this ranking in the second stage. Of course, the same applies to the group of the last 5.

Tab. 2.5 Values of Expansion potential

Material	Expansion potential			
	2000	Ranking	2010	Ranking
Composite	347	1	469	1
Ceramic	186	2	240	3
Metal	140	3	228	5
Polymer	138	4	246	2
Semiconductor	107	5	232	4
Alloy	90	6	183	6
Glass	58	7	129	8
Biomaterial	37	8	133	7
Advanced	7	9	10	10
Nanomaterial	-	10	54	9

The last variable to be calculated is the patent power, that along with the expansion potential contributes to estimating the technology scope. Here again, it is necessary to use the data for the IPC classes, but this time is considered the sum of all the classes on the total number of patents observed. The resulting index is useful for estimating on average how many sectors of the economy are targeted at the patents of the examined technology. The results are listed in table n 2.6.

Tab. 2.6 Values of Patent power

Material	Patentpower			
	2000	Ranking	2010	Ranking
Biomaterial	5,04	1	5,95	1
Polymer	5,02	2	4,67	2
Composite	4,82	3	4,55	3
Glass	4,08	4	4,13	4
Alloy	3,80	5	4,08	6
Semiconductor	3,49	6	3,72	8
Metal	3,44	7	3,84	7
Ceramic	3,05	8	3,41	9
Advanced	2,17	9	2,29	10
Nanomaterial		10	4,11	5

The results of the previously estimated variables in the two survey periods are summarized in Tables 2.7 and 2.8. As can be seen rank positions vary considerably considering the different variables and the Condorcet method is applied to merge together the results of different target technologies.

Tab. 2.7 Results of estimated indexes until 2000

Material	Technology diffusionspeed	Rank	Patentpower	Rank	Expansion potential	Rank
Advanced	34,00	2	2,17	9	7	9
Alloy	18,16	5	3,80	5	90	6
Biomaterial	66,84	1	5,04	1	37	8
Ceramic	10,94	9	3,05	8	186	2
Composite	19,47	4	4,82	3	347	1
Glass	12,59	7	4,08	4	58	7
Metal	11,47	8	3,44	7	140	3
Nanomaterial	-	-	-	-	-	-
Polymer	15,93	6	5,02	2	138	4
Semiconductor	26,79	3	3,49	6	107	5

Tab. 2.8 Results of estimated indexes of the whole period

Material	Technology diffusionspeed	Rank	Patentpower	Rank	Expansion potential	Rank
Advanced	28,20	2	2,29	10	10	10
Alloy	13,05	6	4,08	6	183	6
Biomaterial	40,44	1	5,95	1	133	7
Ceramic	9,94	8	3,41	9	240	3
Composite	14,23	4	4,55	3	469	1
Glass	10,73	7	4,13	4	129	8
Metal	9,00	9	3,84	7	228	5
Nanomaterial	8,57	10	4,11	5	54	9
Polymer	13,47	5	4,67	2	246	2
Semiconductor	26,61	3	3,72	8	232	4

In the Condorcet method each technology is considered a candidate and the result of each criterion is considered a vote. Then, pairwise comparisons are performed to find the total number of wins, losses, and ties for each technology. Each complement pair is compared to the other to assign a point in the "Winner" column for the winner, a point in the "Lose" column for loser and a point for a tie based on the result of each comparison. The Condorcet method can be used with at least two criteria and two alternatives, and different authors use it to merge resulting from different indicators[125].

Table 2.9 shows the results of the comparisons between the various pairs and in the tab 2.10 the final ranking according to the Condorcet method of the first period.

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[125] Nuray R., Can F. “Automatic ranking of information retrival systems using data fusion” Information Processing & Management 42, (2006)

Tab. 2.9 Pairwise comparison until 2000 according to Condorcet method

Material	Advanced	Alloy	Biomaterial	Ceramic	Composite	Glass	Metal	Polymer	Semiconductor
Advanced	-	W	W	W	W	W	W	W	W
Alloy	L	-	W	L	W	L	L	W	W
Biomaterial	L	L	-	L	L	L	L	L	L
Ceramic	L	W	W	-	W	W	W	W	W
Composite	L	L	W	L	-	L	L	L	L
Glass	L	W	W	L	W	-	L	W	W
Metal	L	W	W	L	W	W	-	W	W
Polymer	L	L	W	L	W	L	L	-	L
Semiconductor	L	L	W	L	W	L	L	W	-

Tab. 2.10 Ranking of target technologies in the first period

Material	W	L	T	FinalRank
Biomaterial	8	0	0	1
Composite	7	1	0	2
Polymer	6	2	0	3
Semiconductor	5	3	0	4
Alloy	4	4	0	5
Glass	3	5	0	6
Metal	2	6	0	7
Ceramic	1	7	0	8
Advanced	0	8	0	9

The results and rankings for the second period are set out in the next page.

Tab. 2.11 Pairwise comparison of the whole period according to Condorcet method

Material	Advanced	Alloy	Biomaterial	Ceramic	Composite	Glass	Metal	Nanomaterial	Polymer	Semiconductor
Advanced material	-	W	W	W	W	W	W	W	W	W
Alloy	L	-	W	L	W	L	L	L	W	W
Biomaterial	L	L	-	L	L	L	L	L	L	L
Ceramic	L	W	W	-	W	W	L	L	W	W
Composite	L	L	W	L	-	L	L	L	L	L
Glass	L	W	W	L	W	-	L	L	W	W
Metal	L	W	W	W	W	W	-	L	W	W
Nanomaterial	L	W	W	W	W	W	W	-	W	W
Polymer	L	L	W	L	W	L	L	L	-	L
Semiconductor	L	L	W	L	W	L	L	L	W	-

Tab. 2.12Ranking of target technologies in the whole period

Material	W	L	T	FinalRank
Biomaterial	9	0	0	1
Composite	8	1	0	2
Polymer	7	2	0	3
Semiconductor	6	3	0	4
Alloy	5	4	0	5
Glass	4	5	0	6
Ceramic	3	6	0	7
Metal	2	7	0	8
Nanomaterial	1	8	0	9
Advanced material	0	9	0	10

At the end of this paper, the results of the two-periods forecast activity are compared to check the accuracy of the applied method. The tab 2.12 shows the results compared; the "a" indicates the ranking of the forecast made in 2000, while "b" the results for 2010.

Tab. 2.12 Comparison of ranking results between the two periods

		Forecast 2000									
	Materials	Biomaterial	Composite	Polymer	Semiconductor	Alloy	Glass	Ceramic	Metal	Advanced	Ranking
Forecast 2010	Biomaterial	ab									1
	Composite		ab								2
	Polymer			ab							3
	Semiconductor				ab						4
	Alloy					ab					5
	Glass						ab				6
	Ceramic							b	a		7
	Metal							a	b		8
	Advanced material									ab	9
	Ranking	1	2	3	4	5	6	7	8	9	

2.7 Discussion

To forecast the success of a technology is not an easy task due to the limited information and the continuous market evolutions. The proposed paper is based on patents information processing, often used in economic literature to evaluate innovations, and Altuntas et al. methodology about technology forecasting. The approach presented is a good starting point for assessing investment alternatives.

As already stated this methodology refers to technologies in the state of growth respect to their life cycle and estimate two aspects: the diffusion potential and the technological scope. These criteria have been preferred according to their relevance in the assessment during the maturity phase, therefore if estimate in advance the future development of technology could be envisaged.

During the study, four variables were estimated: technology lifecycle, technology diffusion speed, patent power, and patent expansion. To asses these aspects before investing can lead to many benefits and adopt a homogeneous approach to compare alternatives is certainly a desirable aspect within a strategy. After the indices estimation, the Condorcet method is used to combine the results.

At the end of the procedure a ranking of technologies is obtained.

The technologies under consideration in this work are those of new materials, which represent significant economic sectors of interest in the scientific literature. In detail, has been investigated a ranking of technologies in the following sectors: Advanced Materials, Alloys, Biomaterials, Ceramics, Composites, Glasses, Metals, Nanomaterials, Polymers and Semiconductors. During the data collection, the Nanomaterials category did not reach in the first period enough data for processing and therefore did not return to the final ranking. Nevertheless, given the industry's relevance, the indexes were estimated in the second period and high levels of patent power were assessed.

The best technologies are Biomaterials, Composites and Polymers, intermediate Semiconductors, Alloys and Glasses, and in the latest Ceramics, Metals and Advanced materials.

There are some limitations to this study. First of all, the proposed method assumes that the best time to evaluate a new technology is during the growth phase of its life cycle and all the results are subject to this condition. The future research may also take account of the other lifecycle phases in order to reduce the risk of boosting incremental innovations at the expense of radical ones.

Secondly, patents were selected only on the basis of the title. In the preliminary stages attempts were made to include abstract selection criteria, but the selected patents were too wide-ranging and therefore were discarded. This could led to distortions in certain categories, especially in Advanced Materials, which during the research queries tests showed the greatest oscillations.

Another advisable development for the future is to integrate this methodology with economic indicator such as R&D and marketing expenses, the break-even point, the enabling technologies, the availability of raw materials and qualified manpower, etc.

Finally, the implementation of a new technology within the company and its impact on costs and performance should be taken into account.

CHAPTER THREE

MULTITECHNOLOGY FIRMS, AGE AND PERFORMACE IN NEW MATERIALS SECTORS

3.1 Introduction

The development of new technologies has been recognized as one of the key factors for business profitability and growth in fast changing environments, especially in new material[126]. In economic literature have been developed several indicators to assess technology innovation and its potential development and between these patent data seems to be an objective and mature indicator[127].

Some authors argue that innovation is a "process initiated by the perception of a new market and/or new service opportunity for a technology-based invention which leads to development, production, and marketing tasks striving for the commercial success of the invention[128]."

In order to protect the invention property and facilitate an economic return, meaningful of the invested resources, the legislator recognizes inventors a legally guaranteed competitive advantage over a limited period of time which protects

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[126] Martino, J.P "Technological forecasting for decision making" third ed. McGraw-Hill, New York (1993)

[127] Caselli, F., Coleman, W.J. "Cross-country technology diffusion: the case of computers" American Economic Review 91, (2001)

[128] Garcia, R., Calantone, R. "A critical look at technological innovation typology and innovativeness terminology: a literature review" Journal Product Innovation Management 19, (2002)

almost monopolistic rentals.[129] Therefore if the inventor company decides to exploit the new competitive advantage internally, perhaps by developing new products, or deciding to grant it to others by gaining licenses would lead an economically positive result anyway. However, literature evidences about patents contribution to business performance appear to be conflicting. Some studies found that patents have a positive impact on business performance[130], while others find this effect only in specific cases[131], or do not identify any significant impacts[132]. However, may be inferred two points on the contribution of patents to the company's performance: by the prospect of business performance patents have a strategic contribution if there are competitors in the same technology sector to justify legal protection. If there are no risks of imitating the patenting costs would not be justified. Secondly, to grant a patent means make public all the patent-

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[129] Andries, P., Faems, D. "Patenting activities and firm performance: does firm size matter?" Journal of Product Innovation Management 30, (2013)

[130] Ernst, H. "Patent applications and subsequent changes of performance: evidence from time-series cross-section analyses on the firm level" Res. Policy 30, (2001); Helmers, C., Rogers, M. "Does patenting help high-tech start-ups?" Res. Policy 40, (2011)

[131] Mansfield, E. "Patents and innovation: an empirical study" Management Science 32, (1986); Arora, A., Ceccagnoli, M., Cohen, W.M. "R&D and the Patent Premium" Working Paper N. 9431, National Bureau of Economic Research, Cambridge, (2003).

[132] Griliches, Z., Hall, B.H., Pakes, A. "R&D, patents and market value revisited: is there a second (technological opportunity) factor?" Economics of Innovationand New Technology 1, (1991); Suh, D., Hwang, J. "An analysis of the effect of software intellectual property rights on the performance of software firms in South Korea" Technovation 30, (2010)

related documentation, enabling competitors to acquire new capabilities and increasing the risk of being imitated[133].

This paper investigates how granted patents, firm age and technology domains capabilities of new materials firms influence company performance in the time windows from 2008 to 2015. This paper contributes to scientific literature, firstly, supporting previous studies that hold a general positive effect on the patenting firm's economic performance, secondly, contributing on studies about firm age, and technology domains capabilities on firm performance.

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[133] Levin, R.C., Klevorick, A.K., Nelson, R.R., Winter, S.G., Gilbert, R., Griliches, Z. "Appropriating the returns from industrial research and development" Brooking Papers on Economic Activity 18, (1987)

3.2 Sample

The dataset was created during autumn 2016, subsequently updated in September 2017, by extracting data from the electronic database Amadeus (Bureau van Dijk) on patents relating 10 categories of new materials and on financial statements of European undertaking which own the selected patents.

The European market is particularly interesting for studying the role of patents in firm performance. The innovation policy of several member countries focuses on strengthening ranks to become part of innovation leaders[134]. The database includes information on each company's patents (date of granting and international patents classification) and the company (return on assets, date of incorporation, profit / loss and turnover performance indicators). We argue that these companies are technology-based companies, as their active patenting has shown that a part of their business activities is based on technology.[135]

At first 108,629 patents were extracted from the database. Due to missing values and keeping only those with the granted status the final sample was reduced to 21.454 patents.

In the first phase, the patent titles were selected using as research queries "kind of material" and the word "material". For example, for semiconductor patents, have

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[134] European Commission “Innovation Union Scoreboard 2015” 10.2769/247779, (2015)

[135] Lee, C., Lee, K., Pennings, J.M. “Internal capabilities, external networks, and performance: a study on technology-based ventures” Strategic Management Journal 22, (2001); Storey, D., Tether, B.S. “New technology based firms in the European Union: an introduction” Research Policy 26, (1998)

been included in patents title criteria the following logic operators “Semiconductor” and “material”. This procedure has been repeated for the following types of material: Advanced materials, Alloys, Biomaterials, Ceramics, Composites, Gasses, Metals, Nanomaterials, Polymers, Semiconductors.

In the year 2017, the companies included in the sample have an average of 42 years, from a minimum of 2 to a maximum of 203 years. These companies are active in many sectors and in all European regions.

3.3 Measures

Firm performance

The dependent variable of this paper is firm performance. Companies can patent for several reasons and the goals of patenting can be quite diverse. In addition, as seen above, strategies to improve business performance, through patents, may differ from developing new products to increasing revenues by licensing. However, whatever adopted strategy, the intent is to plan for success in the competition that is noticeable in the performance result. Therefore, is adopted a general performance indicator, firm performance, as a response variable. The idea that, as a last resort, patenting should affect the company's performance supports this choice.

In this paper is used as a proxy the Return on Assets index (Roa) to measure the company's performance[136]. Roa is an adequate impact of patents indicator on business performance, as it shall take into account the patenting and maintaining costs[137]. In general, the turnover generated by patenting should exceed the costs and accordingly have a positive effect on firm’s net income.

Roa values are adjusted with the yearly median values to enhance the comparison between sectors and years.

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[136] Carton, R.B., Hofer, C.W. “Measuring Organizational Performance-metrics for Entrepreneurship and Strategic Management Research”. Edward Elgar, (2006)

[137] Andries, P., Faems, D. “Patenting activities and firm performance: does firm size matter?” Journal of Product Innovation Management 30, (2013)

Number of patents

This first explanatory variable comprises the number of patents that each firm granted and maintained during the time window of observation.

Patent power

This second explanatory variable is defined at firm level as the total number of IPC codes included in retrieved patents over the total number of patents. The patent power denotes that patents relate to a high number of sectors and therefore has a greater potential for creating new economic sectors.

Expansion potential

This third explanatory variable, that coincides with the number of IPC classes on firm’s portfolio, asses if patents held by companies can contribute to further innovations, as it relates to a large number of sectors, since the development of technology leads to the advance of associated technologies.

Firm age

This control is measured as the number of years since their initial founding year. The data source for the founding year is Amadeus (Bureau Van DijK).

Employees

The total number of employees is used as a proxy for firm size. Past researchers in the biotech field make the point that larger firms are more likely to be effective at innovation. Although firm size is often measured in revenues or market share, most biotech firms do not have significant revenue streams in their early stages, thus making the measure inappropriate in this sector[138]

Corporate

The weight of the different attributes of corporate governance is likely to change across the stages of firm evolution. Some authors suggest that individual governance provisions such as independence, accountability and transparency can have differential importance at different moments[139].

This measure helps to control the firm age according to whom hold that mature firms are likely to be characterized by increasing cash flows and decreasing investment opportunities that would stimulate over investments in risky projects with uncertain paybacks (such as innovation projects).

Multi-technology capability: All firms involved in this paper are new materials' technologies related and this variable helps to control the expansion potential.

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[138] Shan W., Walker G., Kogut B. "Interfirm cooperation and startup innovation in the biotechnology industry" Strategic Management Journal 15, (1994)

[139] O'Connor T., Byrne J. "Governance and the Corporate Life-Cycle" International Journal of Managerial Finance 11, (2015)

Multi-technology is allocated as the quantity of new materials' technological domains owned by companies at the beginning of the observation window. Accordingly, taking into consideration the number of new materials under investigation, the range of the variable is from 1 to 10.

3.4 Analytic strategy

The analytic methods consist in a two-step linear regression model, using the ordinary least squares (OLS) estimator with heteroskedasticity-consistent (robust) standard error. The response variable in both estimations is the patenting firm performance.

In the first step, we regressed firm performance against all the control variables without fixed effects. The purpose is to verify whether the company's investment in several technological sectors and the patents development with a broad technological spectrum have a positive effect in terms of economic performance. With this in mind, it is expected that the development of routine and consolidated information flows within companies can contribute to better grasping market opportunities. These arguments lead us to H1.

H1: The higher the number of IPC average classes per patents and the number of technology classes on firm's portfolio the better the economic performance.

The second step includes the number of technological sectors fixed effect in which the company operates, estimated on the basis of patent's portfolios owned by the observed companies. In this case it is expected that the presence in several technological sectors has a positive effect on the company's performance. Further to the previous point, it is expected that among the similar companies the best-specialized company will register the best performance. We, thuse, proposed the following hypotheses:

H2a: The greater the number of technological sectors in which the company is present, the better results will be in terms of performance.

H2b: Within the same number of technological sectors group in which the company is present, the lower the number of IPC average classes in the patents and technological classes on firm's portfolio the better the economic performance

Further details on this topic are provided on chapter one.

3.5 Results

Table 1 shows the minimum (Min), maximum (Max), mean (Mean), standard deviations (SD) and correlations of all the model variables. There are no high correlations between the variables, suggesting that there is no serious multicollinearity. The variable inflation factor (VIF) scores (Table 2) in the regression analysis support this conclusion, as the highest VIF score of 1,65 is clearly below the conventional threshold of 10 for multi-collinearity. The models (see Table 2) are highly significant in all specifications.

In the first step, we regressed firm performance against all the control variables without fixed effects. The results show all the observed variables significant, with the only exception of Employees.

The patent power and expansion potential are both significant and denote a weak positive effect on firm performance (ß = 0,0044 and p = .001) the first and (ß = 0.0001 and p = .007) the second. This finding supports the H1 which assert: the higher the number of IPC average classes per patents and the number of technology classes on firm's portfolio the better the economic performance.

The same can be asserted for firm age, highly significant and positive (ß = 0,0001 and p = .000), since companies develop routines for innovative behavior and become more efficient over time in executing these operations while corporate, highly significant and negative (ß = -3.14e-06 and p = .000), confutes that mature firms are likely to be characterized by increasing cash flows and decreasing investment opportunities.

In the second model is included the number of technological sectors fixed effect in which the company operates, estimated on the basis of patent's portfolios owned by the observed companies.

The results reveal all the variables remain significant except for the patent power and firm age which are explained by the last added effect. The Multi-technology shows always significant values, except for levels 2 and 4, indicating an ever increasing and significant trend that, although interrupted in level 9, confirms the hypothesis H2a which assert: the greater the number of technological sectors in which the company is presented, the better results will be in terms of performance.

The expansion potential is highly significant and negative (ß = 0,0002 and p = .000) corroborating that among the similar companies the best-specialized company register the best performance and verify the hypothesis H2b: within the same number of technological sectors group in which the company is present, the lower the number of IPC average classes in the patents and technological classes on firm's portfolio the better the economic performance.

Tab. 3.1 Descriptive statistics of variables

	Variables	Mean	S.d.	Min	Max	Obs	1	2	3	4	5	6	7	8	9	10
1	Firm performance	5,34	14,88	-6,6	103,83	58.354	1									
2	Firm performance L1	5,34	45,48	-978,25	8.150	50.154	0,323	1								
3	N. of patents	76,45	347,64	1	39.386	58.354	0,198	0,045	1							
4	Multi-technology	3,89	2,61	1	9	58.354	0,18	0,054	0,198	1						
5	Firmage	42,43	29,21	1	202	58.268	0,126	0,044	0,138	0,061	1					
6	Employees	459,62	1.635,05	0	91.800	51.697	0,435	0,375	0,26	0,109	0,114	1				
7	Corporate	148,67	655,70	0	14.035	58.331	0,102	0,036	0,087	0,084	0,022	0,045	1			
8	Patentpower	0,72	0,29	0	1	57.829	-0,159	-0,077	-0,297	-0,159	-0,038	0,126	-0,042	1		
9	Expansion potential	6,94	7,20	0	64	58.354	0,302	0,092	0,324	0,31	0,245	0,256	0,091	-0,195	1	
10	Listed	1,03	0,19	1	2	58.354	0,181	0,089	0,059	0,061	0,043	0,221	-0,018	-0,053	0,085	1

Tab. 3.2 Ordinary Least Squares regression results

Dependent variable			Performance					
	Model 1			VIF	Model 2			VIF
N. patent	-1.02e-06	0	***	1,28	-9.37e-07	0,001	***	1,3
Patent power	0,0044	0,001	***	1,12	-0,0026	0,098		1,64
Expansion potential	0,0001	0,007	**	1,24	-0,0002	0	***	1,6
Firm age	0,0001	0	***	1,08	0,00002	0,082		1,24
Employees	-4.56e-09	0,841		1,33	-6.24e-08	0,008	**	1,48
Corporate	-3.14e-06	0	***	1,03	-3.17e-06	0	***	1,05
Multi-technology 2					0,0025	0,061		1,45
Multi-technology 3					0,0051	0,001	***	1,42
Multi-technology 4					0,0017	0,262		1,42
Multi-technology 5					0,0064	0	***	1,37
Multi-technology 6					0,0076	0	***	1,41
Multi-technology 7					0,0085	0	***	1,37
Multi-technology 8					0,0090	0	***	1,54
Multi-technology 9					-0,0038	0,05	*	1,65

Significance levels: *p < .05; **p < 0,01; ***p < 0,001.

3.6 Discussion

This study aims to investigate how far and under which conditions patents provide economic advantage over companies. Based on a set of 21.545 patents held by European companies, the impact on Return of assets index was estimated. The empirical analysis confirms expectations based on the previous literature. Evaluating the results emerges that multi-technology aspects, age of business and corporate have a positive effect on performance. Findings also adduce that patenting is an attractive way to translate inventions into economic success. More technological group of patent companies hold in a period, better perform in the next stage: all the firm performances with more than one technological domains improve, with the only exception of the last level that can be read as not really significant. This connotation might be related by the fact that companies in different technological domains have developed routines for innovative behavior and have become more efficient over time in executing these routines.

However, the patent intensity in the same industrial sector is also directly related to the company's performance. This evidence could be explained as an inverse causal result. Consideration should be given to the possibility that firms anticipate the market potential that the industrial sector will develop in the following period. In this case companies would be engaged in innovation-related activities in that particular field. Accordingly, it may not be that innovation competition leads a better firm performance, but rather the anticipation of market potential. This potential could motivate companies to engage in targeted innovation activities that could potentially lead to patents.

Evaluating the multi-technology aspects emerges that his effect on performance is stronger if patents are granted in the same economic area. This dynamic is indicated by the patent power variable, that is negative in the second models reporting that, when increase the average number of technological classes covered by a patent the economic performance has a negative effect.

Indeed, when the multi-technology control is introduced in the model, all variables remain very significant, except for the patent power technology variable and the firm age. The results show that companies performance is constantly increasing as the number of technologies present in the portfolio increase.

In addition, the multi-technology effect reveals that, within homogeneous groups of companies operating in the same number of technological sectors as the number of IPCs in the patent portfolio increases, profitability decreases. This trend shows that there is a risk of loss of profitability in covering more technologies, while companies that focus their technology investments are rewarded.

The connotation of this result could also be explained as a company's defensive action against imitators. The patenting company, in this respect, tends to cover the greatest possible number of technological sectors in order to discourage the entry of new competitors.

CHAPTER FOUR

APPROACH NEW MARKET NICHES: THE MULTI-TECHNOLOGY CAPABILITIES AND THE IMPACT EFFECTS ON INNOVATIVE OUTPUT.

4.1 Introduction

This paper address the issue whether the benefits of expanding the technological capabilities depend on the number of economic sectors in which the company operates. This work is based on the literature of dynamic capabilities to study how the new technologies incorporation impacts on its next innovative activity.

In this regard, it is commonly assumed that start-ups create revolutionary inventions but some evidence suggests that structured companies also generate such discoveries[140]. This paper contributes to this issue by examining the role of entry into new technology sectors and how the effects of the ramifications on innovative activity vary according to the number of previous multi-technology status. To assess whether the technological expansion is affected by the number of sectors, a dataset of 9,917 companies, operating in the advanced materials sector, over the period 1995 to 2016 is examined. Investigating companies patent portfolios and their compositions, it was possible to establish if the firm is

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[140] Dushnitsky G., Lenox MJ. "When do firms undertake R&D by investing in new ventures?" Strategic Management Journal 26, (2005); Phene A., Fladmoe-Lindquist K., MarshL. "Break-through innovations in the U.S. biotechnology industry: the effects of technological space and geographic origin" Strategic Management Journal 27, (2006).

operating in more than one technological field. This condition is verified if an enterprise approaches a new industry, because comes into contact with different technologies and know-how increasing its technological capabilities. The sample structured in this way allows us to assess the impact and evolution of the companies technological output when they approach new market niches. This work integrates the existing literature by examining separately the effects of branching on the quantity of innovative output and the impact that output has on the technology domain.

4.2 Theory

Several authors consider that the birth of new knowledge occurs through a recombination of existing knowledge[141]. Indeed, it can be argued that inventors within companies, generating new products, combine the technologies they already know, thus limiting possible outputs to the currently available knowledge[142]. The entry into a "new to the firm" domain, while increasing the available knowledge, allows the company to increase stock of opportunities. Knowledge components acquired in the new technology domain can then be implemented with the existing one so that new market solutions and products can be introduced[143]. Some authors, in this regard, claim that the variety of problem-solving approaches increases the possibility of finding solutions and avoiding technological bottlenecks. Recombination can also improve the impact of innovation on the domain of technology itself. Indeed, it has been argued that the innovation derives from the recombination of non-obvious technological components[144]. Therefore, the combination of knowledge from different sectors,

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[141] Basalla G., "The Evolution of Technology" Cambridge University Press, (1988); Henderson R., Cockburn L. "Measuring competence? Exploring firm effects in pharmaceutical research" Strategic Management Journal15, (1994); Schumpeter J.A. "Business Cycles". McGraw-Hill, (1939).

[142] Fleming L. "Recombinant uncertainty in technological search." Management Science 47, (2001); Fleming L., Sorenson O. "Science as a map in technological search" Strategic Management Journal25, (2004).

[143] George G., Kotha R., Zheng Y. "The puzzle of insular domains: a longitudinal study of knowledge structuration and innovation in biotechnology firms" Journal of Management Studies45,(2008)

[144] Basalla G. "The Evolution of Technology" Cambridge University Press, (1988)

increase the chances of finding new solutions, could lead to the production of radical innovations that could potentially affect both, the source and acquired sectors[145].

However, shall be taken into account that entering simultaneously into multiple technological niches requires an important effort to experiment and understand new technological domains. When companies enter multiple domains simultaneously, they face difficulties in absorbing new technologies and in maximizing the contributions of multiple knowledge[146].Therefore, although acquiring different knowledge can provide new tools for solution and design, without proper understanding and control of new knowledge, the effect is likely to be counterproductive. Then in order to pursue a positive effect, it's advisable for companies to develop a thorough knowledge of new technologies and market niches. Incorporating new skills usually requires time investment and considerable effort to manage the involved resources. Consequently, it is reasonable to expect companies operating in different sectors to be more capable in technological management and to behave better, in terms of innovative production and technology impact comparing, to those that manage few domains.

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[145] Ethiraj S., Puranam P., "The distribution of R&D effort in systemic industries: implications for competitive advantage." Business Strategy over the Industry Lifecycle, Advances in Strategic Management 21, (2004)

[146] Cohen W.M., Levinthal D.A. "Absorptive-capacity: a new perspective on learning and innovation" Administrative Science Quarterly 35, (1990)

Some authors argued that accumulation of knowledge improves a company's ability to acquire, assimilate, and exploit information to generate further innovations[147]; others that the availability of resources can positively influence the innovative production of a company and support it to explore new areas of growth[148]. Another aspect to be taken into account is the presence of functional infrastructure for innovation, such as research laboratories and scientific human capital, which are important resources for increasing the potential reception of information.

By way of conclusion, should be considered the communication of tacit technological information that is crucial to innovation. Information flows in a small firm are simpler, as the number of employees is lower and decision-making systems are fluid and transparent, allowing complete communication and cohesion with the management team. On the other hand, the more structured companies, with more specialized staff, can develop a greater understanding of its technological domain and it can allow to recombine new knowledge more efficiently. These companies, through their own technological efforts, develop a deeper understanding of limits in component recombination. This experience helps multi-sector companies avoid "dead ends" and makes them less likely to pursue unsuccessful innovation. Therefore, it can be assumed that approaching

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[147] Nohria R., Gulati "Is slack good or bad for innovation?" Academy of Management Journal 39, (1996).

[148] Penrose E. "The Theory of the Growth of the Firm" Oxford University Press, (1959).

new market niches has a greater technological impact on the innovative production for companies that operate in different sectors than those less structured.

New material sectors are an appropriate context to test theories of innovation as performance is largely dependent upon the firms' technological capabilities[149]. Details on patents and new materials literature can be found in chapter one.

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[149] Kotha R., Zheng Y., George G. "Entry into new niches: the effects of firm age and the expansion of technological capabilities on innovative output and impact." Strategic Management Journal 32, (2011); Phene A., Fladmoe-Lindquist K., Marsh L. "Breakthrough innovations in the U.S. biotechnology industry: the effects of technological space and geographic origin" Strategic Management Journal 27, (2006); Huang K.G., Murray F. "Does patent strategy shape the long-run supply of public knowledge? Evidence from human genetics." Academy of Management Journal 52, (2009)

4.3 Sample

The data was collected from the database Amadeus (Bureau Van Dijk) updated on 17 October 2017. The sample include longitudinal data of 9.917 European companies operating with advanced materials technology and more generally in the new material sectors. In the first phase patent data were collected relating to the following sectors: Advanced Materials, Alloys, Biomaterials, Ceramics, Composites, Glasses, Metals, Polymers, Semiconductors. In the research process were used research queries, addressed to titles patents, structured as follow: "kind of material" and "material." For example, to select Alloys patents, has been set the keywords "Alloy" and "material." Before adopting these search criteria, several tests were also carried out with WIPO (World Intellectual Property Organization) and EPO (European Patent Office) databases; "Amadeus" was selected for greater accessibility of owner companies' data.

The second phase involved the identification of owner companies and the patent portfolios survey per enterprise. Consistent with other studies, the foundation year for all firms has been collected[150]. Afterwards were verified whether companies occur in more technological sectors among those investigated.

The following table shows some sample composition statistics.

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[150] George G., Zahra S., Wood D. "The effects of business-university alliances on innovative output and financial performance: a study of publicly traded biotechnology companies" Journal of Business Venturing 17, (2002)

Tab. 4.1 Description by county and listed status of the sample

Countries	Listed companies														Total						
	No							Yes													
	Firms	Patents*	Citing doc *	IPC classes*	Cited doc*	Invested mat*	Age*	Firms	Patents*	Citing doc *	IPC classes*	Cited doc*	Invested mat*	Age*	Firms	Patents*	Citing doc *	IPC classes*	Cited doc*	Invested mat*	Age*
Austria	260	14,44	16,08	40,30	35,39	4,03	46,03	9	18,67	10,44	60,11	27,56	4,33	63,89	269	14,58	15,89	40,96	35,13	4,04	46,63
Belarus	2	8,5	0,5	26	4	2,5	22	-	-	-	-	-	-	-	2	8,5	0,5	26	4	2,5	22
Belgium	97	21,39	21,45	75,26	34,97	4,47	37,32	11	2,45	2,64	8,73	55,45	4,18	46,64	108	19,46	19,54	68,48	37,06	4,44	38,27
Bulgaria	9	5,78	1	14,78	1,22	2,22	112	2	12	1	23,5	6	2,5	112	11	6,91	1	16,36	2,09	2,27	112
Croatia	1	4	-	5	-	3	22	-	-	-	-	-	-	-	1	4	-	5	-	3	22
Cyprus	3	18,67	69,33	91,67	28,67	2,33	18,33	-	-	-	-	-	-	-	3	18,67	69,33	91,67	28,67	2,33	18,33
Czech Republic	118	15,42	2,7	36,6	11,19	3,35	22,99	-	-	-	-	-	-	-	118	15,42	2,70	36,6	11,19	3,35	22,99
Denmark	124	10,84	19,4	39,6	32,35	3,52	28,52	10	2,8	12,7	10	42,6	4,7	52,6	134	10,24	18,90	37,4	33,12	3,6	30,31
Estonia	2	3,5	-	5	-	4	24	-	-	-	-	-	-	-	2	3,5	-	5	-	4	24
Finland	227	15,83	26,44	63,19	24,18	3,55	29,61	24	13	20,63	52,17	34,58	3,46	46,58	251	15,56	25,89	62,14	25,18	3,54	31,23
France	907	16,58	20,83	59	24,37	3,84	36,19	63	40,98	53,97	136,83	44,24	4,76	44,37	970	18,16	22,98	64,05	25,66	3,9	36,72
Germany	3.324	14,91	23,78	45,73	34,53	3,69	51,39	74	19,54	25,74	59,09	51,62	4,96	59,8	3.398	15,01	23,83	46,02	34,9	3,72	51,58
Greece	4	11,25	13	19	33,25	5,75	112	1	7	-	33	1	6	112	5	10,4	10,4	21,8	26,8	5,8	112
Hungary	17	5,12	1,24	16,71	2,24	2,94	32,41	1	1	2	3	4	8	94	18	4,89	1,28	15,94	2,33	3,22	35,83
Iceland	3	8	1,67	26,67	4,67	2,33	23,67	1	2	56	5	99	8	46	4	6,5	15,25	21,25	28,25	3,75	29,25
Ireland	30	9,2	35,4	51,77	55,2	4,1	24,53	1	1	18	1	48	8	25	31	8,94	34,84	50,13	54,97	4,23	24,55
Italy	1.399	10,12	9,1	29,31	17,25	3,31	32,12	32	5,63	4,44	19,47	27,84	3,88	37,88	1.431	10,02	9	29,09	17,49	3,32	32,25
Latvia	4	7	1,75	10	0,5	1	24,75	-	-	-	-	-	-	-	4	7	1,75	10	0,5	1	24,75
Liechtenstein	9	10,44	13,56	36,11	41,44	3,67	39,44	-	-	-	-	-	-	-	9	10,44	13,56	36,11	41,44	3,67	39,44
Lithuania	2	46,5	4,5	60,5	-	5	19	-	-	-	-	-	-	-	2	46,5	4,5	60,5	-	5	19
Luxembourg	22	5,77	9,23	21,77	24,95	4,55	37,82	-	-	-	-	-	-	-	22	5,77	9,23	21,77	24,95	4,55	37,82
Macedonia (Fyrom)	-	-	-	-	-	-	-	1	2	14	4	11	2	71	1	2	14	4	11	2	71
Malta	1	9	39	58	41	3	25	-	-	-	-	-	-	-	1	9	39	58	41	3	25
Netherlands	316	15,19	29,27	51,07	48,51	3,51	40,09	6	4	12	24	51	5	35,17	322	14,98	28,95	50,57	48,56	3,54	40
Norway	95	10,21	17,38	29,04	26,63	3,09	21,82	15	8,2	40,87	28,8	42,27	3,27	22	110	9,94	20,58	29,01	28,76	3,12	21,85
Poland	99	23,59	1,67	57,75	2,42	3,18	112,02	6	18,5	0,33	37,67	1,67	3,17	112	105	23,3	1,59	56,6	2,38	3,18	112,02
Portugal	19	12,42	1,89	104,37	16,16	3,89	39,95	2	8,5	1	53	4	2,5	60	21	12,05	1,81	99,48	15	3,76	41,86
Romania	2	11	-	15,5	-	4,5	112	1	26	1	45	-	7	112	3	16	0,33	25,33	-	5,33	112
Russian Federation	101	15,36	4,28	29,11	2,57	3,82	31,21	8	14,63	4	28	0,88	4,88	55,38	109	15,3	4,26	29,03	2,45	3,9	32,98
Serbia	1	8	-	28	-	6	57	-	-	-	-	-	-	-	1	8	-	28	-	6	57
Slovakia	10	6,60	2,5	23	8	3,5	22,1	1	1	7	2	1	8	25	11	6,09	2,91	21,09	7,36	3,91	22,36
Slovenia	23	8,17	2,26	29,26	4,91	3,91	24,96	1	2	-	4	2	2	43	24	7,92	2,17	28,21	4,79	3,83	25,71
Spain	448	13,05	4,34	34,07	8,01	3,3	36,02	19	5,32	2,37	14,84	12,63	4,26	56,37	467	12,73	4,26	33,28	8,2	3,34	36,85
Sweden	314	14,21	25,26	54,43	32,16	3,72	41,16	47	16,7	93,57	59,36	63,34	4,64	34,32	361	14,54	34,16	55,07	36,22	3,84	40,26
Switzerland	489	12,29	25,61	47,75	42,1	3,98	43,28	19	34,63	78,58	186,84	85,79	5,26	54,63	508	13,12	27,59	52,95	43,74	4,02	43,71
Turkey	19	9,21	0,47	10,53	0,16	3,21	25,84	1	1	-	-	-	8	62	20	8,8	0,45	10	0,15	3,45	27,65
Ukraine	8	3,13	-	5,88	-	3,88	112	4	14,25	2	28,25	-	4,75	112	12	6,83	0,67	13,33	-	4,17	112
United Kingdom	1.004	17,6	55,59	81,56	61,08	3,99	42,33	40	17,83	34	68,75	75,55	4,43	41,98	1.044	17,61	54,76	81,07	61,63	4,01	42,31
n.s.	4	22,75	22,5	82	12,75	4,25	64,5	-	-	-	-	-	-	-	4	22,75	22,5	82	12,75	4,25	64,5
Total	9.517	14,37	22,84	48,34	31,72	3,67	42,72	400	18,79	35,79	65,92	46,56	4,51	49,01	9.917	14,54	23,36	49,05	32,32	3,7	42,98

* Data are in average

The table shows that the largest number of companies belong respectively to Germany, Italy, the United Kingdom and France. The observed values, sorted by country of origin, show a rather heterogeneous framework because, depending on the observed variable, there are remarkably different scenarios. The table also indicate that the 400 listed companies have the highest results on average in all the observed categories.

This paper has a 21 years' observation window, from 1995 to 2016. It has been chosen to limit the observation period both for avoid censoring problems due to incomplete observations and for maintain a stronger sector characteristics consistency between the beginning and the end of the observation period. Finally patent citations and IPC (International patent classification) classes data were collected.

4.4 Variable Definitions

In this paper patent data are used to assess the development of technological capability within companies. The analysis is based on following data: patent filing year, quantities and typologies of IPC classes, names of current owners. The selected patents have been used to identify outcomes of research and development (R&D) activities, patents have also been used extensively to capture technological capabilities or portfolios[151].

Quantity of innovative output: is the dependent variable of this model. The amount of innovative production is estimated as the number of new patents granted in two subsequent years (t + 1, t + 2). The use of patents to study firm-level novelty is often adopted. For example, drug development includes a complex approval process that lasts an average of 12 years[152]. Consequently, relating entry into new technological domains with the new patent applied but not registered may prove useless. It should also be taken into account that markets are only able to assess patents following registration. Therefore, granted patents and citation levels allow us to assess the use and creation of knowledge and also to correlate the firm economic value. The criteria for receiving patent, as described

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[151] Argyres N.S., Silverman B.S. "R&D, organization structure, and the development of corporate technological knowledge" Strategic Management Journal 25, (2004); Zheng Y, Liu J., George G. "The dynamic impact of innovative capability and inter-firm network on firm valuation: a longitudinal study of biotechnology start- ups." Journal of Business Venturing 25, (2010).

[152] Hall B.H., Jaffe A., Trajtenberg M. "Market value and patent citations" RAND Journal of Economics 36, (2005)

in the EPO and WIPO guides, are that each invention should be new, trivial, and have a commercial application. The innovative output variable has a mean value of 1,33 and a standard deviation of 5,87.

Multi-technology: All firms involved in this paper are new materials' technologies related. This explanatory variable is allocated as the quantity of new materials' technological domains owned by companies at the beginning of the observation window. Accordingly, taking into consideration the number of new materials under investigation, the range of the variable is from 1 to 8. Considering the variable under consideration as continuous, we get the following statistics: the mean value observed is 3,7 and the standard deviation 2,46.

Branching: is a count of niches (technological domains) "new to the firm" using as proxy the IPC codes at 4-digit level. This measure reflects the process of expanding the scope of a company's technological skills. Depending on the biennial window for dependent variables, we use the number of entries resulting from a company in the year t-0 and t-1. The mean with the window of two years is 0,42 and has a maximum value of 45.

Technological impact: is measured as the average number of citations received from patents filed by the company in the years t - 0 and t - 1 (quotations received /

patent counts). Most quotes tend to occur within a few years of the patent registration date, peaking in the third year.153 The impact variable has an average value of 1,45 and a standard deviation of 6,47.

Technological framework: is measured using as proxy the number of cited documents on granted patents filed by the firm in the years t - 0 and t - 1 (quotations given / patent counts). This measure helps to control the previous availability of firm technological capability to grab the innovative opportunities.

Distance: this variable refers to an estimate of the closeness of a company's technological branching over time. To estimate this variable, all the patent'sipc classes per year were collected, and then, all the patents held by each company per year were aggregated. In the next step the percentage of each class per company was determined. Finally, the Euclidean distances between these patent class vectors were computed for each firm by comparing it to the previous year. When the value of this variable is zero means that the firm has an identical profile from that of the preceding year; when the value reach1.4 (the square root of two) means that the firm continues to patent in different classes.

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[153] Hall B.H., Jaffe, A., Trajtenberg M. "Market value and patent citations" RAND Journal of Economics 36, (2005).

Knowledge stock: correspond to the number of patents applied in the previous three years. This measure helps to control the availability of resources and the size of the company.

Listed: is a dummy variable that ponder whether is a listed company or not. The stock market feature is used as a proxy to indicate larger size and easier access to financial resources.

Breadth of technological capabilities: is measured as the total number of technological classes in which a company has granted patents before the time window used to assess the branching variable.

Depth of technological capabilities: coincide with the maximum number of patents in each technological class observed during the investigation period.

4.5 Results

Table 4.1 shows the descriptive statistics of key variables for Multi-technology values. It seems clear that all the investigated variables assume higher values as the multi-technology increase, confirming those authors who argue that experiential baggage in handling technologies favors more expertise in developing new knowledge. This theoretical framework is also confirmed by the sharp increase in the branching values that occurs from the lowest Multi-technology class to the highest.

Tables 4.2 give some descriptive statistics and correlations of the model variables. There are no high correlations between the variables, suggesting that there is no serious collinearity. The variation inflation factor scores (Table 4.3) in the regression analysis support this conclusion, as the highest VIF score of 1,47 is clearly below the conventional threshold of 10 for multi-collinearity. Regarding the model n. 3, here again, there are no high correlation scores while the highest VIF is 1,76; even in this model it can be presume that there are no collinearity problems.

The first two models are highly significant in all specifications, with the exception of technology impact and listed that are not significant in any. Below are presented the detailed econometric results:

Tab. 4.1 Descriptive statistics by Multi-technology classes

Variables	Multi-technology 1 to 3 N. firms = 5.292				Multi-technology 4 to 5 N. firms = 1.879				Multi-technology 6 to 8 N. firms = 2.746			
	Mean	S.d.	Min	Max	Mean	S.d.	Min	Max	Mean	S.d.	Min	Max
Innovative output	1,05	5,87	0	156	1,3	4,01	0	160	1,88	9,69	0	588
Technology impact	1,37	5,45	0	297	1,52	5,81	0	213,5	1,54	8,53	0	839
Branching	0,27	0,93	0	44	0,42	1,22	0	38	0,72	1,67	0	45

Tab. 4.2 Descriptive statistics and correlations

	Variables	Mean	S.d.	Min	Max	Obs	1	2	3	4	5	6	7	8
1	Innovative output	1,33	5,87	0	588	198.340	1							
2	Technology impact	1,45	6,47	0	839	62.630	0,008	1						
3	Knowledge_stock	2,07	8,96	0	873	188.423	0,89	0,004	1					
4	Technology framework	3,93	9,76	0	133	62.630	-0,073	0,14	-0,07	1				
5	Branching	0,42	1,25	0	45	208.257	0,12	0,02	0,05	0,12	1			
6	Distance	0,20	0,34	0	1,41	208.257	0,09	-0,01	0,06	-0,01	0,3	1		
7	Breadth	19,25	138,86	0	6.237	204.614	0,36	-0,01	0,45	-0,04	0,003	0,01	1	
8	Depth	5,16	21,49	0	1.800	218.174	0,15	0,03	0,11	0,22	0,32	0,05	0,05	1
9	Multi-technology	3,70	2,46	1	8	218.174	0,06	0,01	0,06	0,12	0,15	0,08	0,16	0,18

Tab. 4.3 Regressions models 1 - 2

Dependentvariable	Innovative output							
	Model 1			VIF	Model 2			VIF
Technology impact	0,004	(.116)		1,02	0,004	(0,118)		1,02
Knowledge_stock	0,559	(.000)	***	1,40	0,559	(.000)	***	1,39
Technology framework	-0,024	(.000)	***	1,07	-0,024	(.000)	***	1,07
Branching	0,775	(.000)	***	1,11	0,776	(.000)	***	1,11
Distance	-0,173	(.000)	***	1,07	-0,175	(.000)	***	1,07
Breadth	-0,002	(.000)	***	1,47	-0,002	(.000)	***	1,45
Listed	0,153	(.119)		1,01	0,065	(0,142)		1,01
Multi-technology 2	0,059	(.306)		1,29				
Multi-technology 3	0,071	(.249)		1,25				
Multi-technology 4	0,066	(.307)		1,23				
Multi-technology 5	0,229	(.001)	**	1,22				
Multi-technology 6	0,268	(.000)	***	1,21				
Multi-technology 7	0,413	(.000)	***	1,20				
Multi-technology 8	0,493	(.000)	***	1,35				
Multi-technology					-1,443	(.000)	***	1,10

Tab. 4.4 Regression model 3

Dependent variable	Performance 2010			
	Model 3			VIF
Innovative output 2005	0,017	(0,097)		1,05
Technology impact 2005	-0,009	(-0,485)		1,11
Knowledge_stock 2005	0.583	(.000)	***	1,76
Technology framework 2005	-0,074	(-0,036)	*	1,12
Branching 2005	1,611	(.000)	***	1,19
Distance 2005	-0,625	(0,006)	**	1,19
Breadth 2005	-0,006	(.000)	***	1,81
Listed 2005	-1,641	(0,005)	**	1,03

Knowledge stock, assessed by the number of patents applied in the previous three years, shows strongly significant (p=.000) but weak positive effects on the quantity of innovative output. Technology framework, on the contrary, is slightly negative

And takes into account the average number of cited documents in the years t - 0 and t – 1. This finding could mean that a higher level of patenting experience in a particular technology domain, regardless the industry innovation level, leads to a stronger patenting performance in the following period. Branching is the number of entries "new to firm" measured as number of IPC classes with the scope to identify the technology domains in year t-0 and t-1. This variable, although with a weak positive effect, strengthens what outlined above. Firms, rooted in a technological sector, develop patents in other domains not necessarily to approach new markets. These findings can be explained in at least two ways: the first, approaching new technology niches favor the development of new knowledge and therefore new patents; the second is that companies, to prevent the entry of new competitors into the market, are seeking patents protection into as many technological fields as possible.

Distance and breadth have a slight negative effect on the innovative output. The first measure assesses the proximity of technology branching by a firm, estimated by calculating the Euclidean difference between the IPC class sets with the previous year; the second represent the total number of classes in which a firm applied for patents before the time window for the construction of the branching variable. These two variables shall reflect the variation in the patent portfolio over time as a whole. The negative effect could be explained by the "new to firm" effect: as the new technology classes percentage increases, in a narrow time of observation, the company needs more time to develop specialized know-how, perceive new niches markets and develop new products, reducing innovative output in later years.

Regarding the multi-technology effect, it is always positive, whether it is discreet or continuous.

In model 3 is no longer takes into consideration the 21-year time window, but 2010 for performance and 2005 for all others. The variable performance is estimated by ebit values adjusted with the median value of the same year divided by 1000. A time gap has been included in order to take into account that companies need time to profit of the new knowledge and therefore get a positive economic feedback.

All observed variables remain significant and confirm their effects, with the exception of Multi-technology and listed. The first one doesn’t present significant dynamics, while the second indicates a moderately negative effect (ß = -1,641). The performance shows a positive effect close to significance (p = 0.017; ß = 0.097).

4.6 Discussion

This study adds to the literature by examining how the multi-technologic capabilities and economic performance affect quantity of innovative activity. The results show the importance of time factor to develop the necessary skills to profit from new technological knowledge. Some authors, in this respect, argue that small businesses face the choice if investing ahead in capacity development, running the risk of excessive deficit, or gradually with losing market potential risks.[154] Others studies doubt of time factor importance in adapting and developing new skills in the more structured companies.[155] Sapienza et al.[156] suggests that investment in developing new capacity to approach the international markets can reduce short-term survival prospects but increase long-term growth potential. Conversely, more structured businesses tend to develop incremental innovations thanks to which enter in new market niches, expanding their technological capabilities and renewing their product and research lines[157]. This study affirms that when companies enter into new technology niches, they have a significant positive impact in terms of new patents in subsequent years. The results confirm other studies conclusions indicating that companies who invest in

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[154] Sapienza H.J., Autio E., George G., Zahra S. "A capabilities perspective on the effects of early internationalization on survival and growth" Academy of Management Review 31, (2006)

[155] Helfat C.E., Peteraf M.A. "The dynamic resource- based view: capability lifecycles" Strategic Management Journal 24, (2003)

[156] Sapienza H.J., Autio E., George G., Zahra S. "A capabilities perspective on the effects of early internationalization on survival and growth" Academy of Management Review 31, (2006)

[157] Ahuja G., Lampert C.M. "Entrepreneurship in the large corporation: a longitudinal study of how established firms create breakthrough inventions" Strategic Management Journal 22, 2001

the development of technology capabilities earlier, experience higher performance in the subsequent period. Therefore, the time in which technological expansion investments are made influence the future level of profits.

Companies that operate in multiple domains, entering into new niches, are able to develop a greater extent of innovative product than those one manage just one. There are several models that study technological expansion in relation to organizational structure. In the economic literature, learning from innovation is an important source of competitive advantage[158]. Understanding the technological capabilities of small firms and their ability to generate high-impact inventions is of great interest in entrepreneurship and innovation studies.

Despite the evidence of this study, it suffers from some limitations. First, the resource allocation is controlled through the number of granted patents in the last three years and access to equity markets, while direct measures to quantify the resources availability should be included. Secondly, it is not explained why some companies approach other market niches while others do not. The arguments put forward evaluate the effects of branching on innovative output rather than discerning the logic for approaching specific niches. So there is a lack in our understanding of why businesses are expanding, a useful way for future researches.

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[158] Autio E., Sapienza H.J., Almeida J.G. "Effects of age at entry, knowledge intensity, and imitability on international growth" Academy of Management Journal 43, (2000); Sorensen J.B., Stuart T.E. "Aging, obsolescence, and organizational innovation" Administrative Science Quarterly 45, (2000)

Third, an interesting area for doing research might be to measure and test the relative magnitude of causal mechanisms, such as how resource constraints hinder investment in innovation for companies operating in one sector or routine for that in many industries.

Finally, patent-derived measures are used to assess technological capabilities. The use of patent-based measures captures an important, though partial, aspect of a technological capability. An extension of this study could consider more detailed measures to articulate more explanations on how these companies address their search behavior. Other measures may include, among others, scientist publication data, partner's complementary resources, and capital investment in product development.

This work has estimated the influence of branching on innovative returns for firms. The results come in addition to entrepreneurship literature, suggesting the conditions in which innovative production is influenced by the degree of firm’s multisectorality and economic performance.

Conclusions

It is not easy to know in advance how technological markets evolve in order to set up an economic advantage and to improve firm performance. As already argued in the first part, the increasing importance of innovation is due partially to the globalization of markets: foreign competition has put pressure on firms to continuously innovate in order to produce differentiated products and services.

Introducing new products helps companies to protect their margins while investing in process innovation gives them the opportunity to reduce their costs. These technologies help companies develop and produce more product variants in order to meet with the favour of well-defined customer groups, thus achieving differentiation from competitors. At the same time while producing multiple, costly and time-consuming product variations, flexible manufacturing technologies enable companies to seamlessly transition from producing one product model to the next one, adjusting production schedules with real-time information on demand.

By investigating the sources of innovation it emerges that they can be internal, external, and collaborative; this last one is particularly important in high-technology sectors, where it is unlikely that an individual or an organization will possess all of the resources and capabilities useful to develop and implement a significant innovation.

Each type of innovation gives companies and society different opportunities, demanding different responses from producers, users and market-regulating institutions. In the absence of a shared criterion to distinguish technological innovation forms, some of the criteria used to classify technologies have been listed to understand the factors identifying different types of innovation. The path of technological innovation has been defined as a technological trajectory that is often used to represent its performance improvement and its market adoption process. Although these trajectories can be influenced by many factors, it is possible to identify some evolutionary models found in a variety of sectoral contexts and at different times. A review of the criteria used to distinguish the forms of technological innovation was then elaborated, followed by the description of the S-curve models, which occur very often when observing the trend of technological performance and its dissemination process in market. The proposal found that improving technology performance can stimulate and accelerate its diffusion, while a higher adoption rate may prompt companies to make new investments to further improve technology performance. In order to concern the benefits to achieve, the first company approaching the new market can enjoy the benefits of brand loyalty, technological leadership, low stock option rights and the buyer's switching costs exploitation. However, the development of innovative products and services is risky, because it implies a significant commitment of time and financial resources for companies. It depends on the manager to choose the projects to invest in and subsequently to ensure that they can be carried out in accordance with rigorous development processes. In this regard, it has been developed a wide variety of evaluation method used in business practice as informal or structured, with qualitative or quantitative approaches.

New material sector is a representative actor in the field of innovations. During the discussion it emerged that the different technology sectors they refer to are rapidly evolving to the point of creating new classes, such as the advanced materials. Such rapid evolutions make it difficult for investors to seek concrete clues to get decisions. In this regard, the patent data may be used to predict the success of the technology analyzed in the context of the technology lifecycle, potential diffusion and technology scope. In the first study the data fusion algorithm is applied to combine the results obtained from different criteria. The usefulness and potential of the proposed forecasting approach have been demonstrated using patents related to ten new material classes, as following: Advanced Materials, Alloys, Biomaterials, Ceramics, Composites, Glasses, Metals, Nanomaterials, Polymers, Semiconductors. The results obtained from these patents indicate a ranking of materials where Biomaterials, Composites and Polymers are preferred over other technologies.

In the next step, the aim is to investigate how far and under which conditions patents provide economic advantage over companies. In this phase, company performance is estimated, evaluated by Return on Assets (Roa) index values, using some of the key business features such as: presence in multiple technology sectors, firm age, employees, corporate, quantity of granted patents and two previous work indexes, patent power and expansion potential. Some evidence is founded based on a sample of 21,454 patents associated with the 9 new material technologies. Evaluating the results, it emerges multi-technology aspects, age of business and corporate have a positive effect on performance. Findings also show that patenting is an attractive way to translate inventions into economic success: more technological group of patent companies hold in a period, better perform in the next stage. Evaluating the multi-technology aspects emerges that his effect on performance is stronger if patents are granted in the same economic area. In addition, the multi-technology effect reveals that, within homogeneous groups of companies operating in the same number of technological sectors as the number of IPCs in the patent portfolio increases, profitability decreases. This trend has been described as the risk of loss profitability in covering more technologies, while companies that focus their technology investments are rewarded.

In the last part, the debate is aimed to investigate whether the benefits of expanding the technological capabilities depend on the number of economic sectors in which the company operates. This part of the work studies how the new technology incorporation impacts on firm’s future innovative activity. The sample includes longitudinal data of 9,917 European companies operating with advanced materials technology and, more generally, with new material sectors. The results show the importance of time factor in developing the necessary skills to profit by new technological knowledge. This study affirms that when companies enter into new technology niches they reach a significant positive impact in terms of new patents in subsequent years. The results confirm other studies in literature concluding that companies investing earlier in the development of technology capabilities get higher performance in the subsequent period and those operating in multiple domains that decide to enter into new niches are able to develop a greater degree of innovative product according to those managing just one.

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