II. Technological Activities of Firms: Definitions and Concepts

SUMMARY

The process underlying technological change is very complex. The main objectives of this introductory chapter are to discuss the main determinants and effects of technological change and to address some issues concerning measurement. This review of issues is completed with an illustration of recent patterns of technological activities carried out by large manufacturing firms.
2.1. INTRODUCTION

Before moving on to the empirical analysis of the impact of firms’ technological activities on their economic and technological performances, it is useful to ask some questions about innovative activities carried out by firms. Who does technological activities? What is the order of magnitude of these activities in comparison to other economic ones? How are technological activities performed? What are the forces that induce these activities or for what reasons do firms engage in such activities? What are the technological and economic outcomes of these activities? What role can public authorities play to support or promote these activities?

This chapter aims at giving some answers to these questions. Such an exercise should clarify the objectives of this thesis and will outline some of the limits of the present formalization of the links between technological and economic activities. First, we present some stylized facts about the technological activities carried out by large international manufacturing firms over the past 10 years. Some measures of the technological activities allow to give a better picture of the different patterns of such activities across countries and the rate at which these activities have evolved over the last decade. Yet, some words need to be said regarding the difficulties encountered when measuring the rate of technological activities. Technological change embraces multiple dimensions. Section 2.3 is aimed at shedding some light on some of these dimensions by defining useful concepts such as invention, innovation, diffusion, the types of activities associated with R&D and other sources available to firms in order to acquire and generate new knowledge. What are the determinants that enhance technological change? Though R&D is often considered as a major determinant of technological change, other firm, industry, or country specific factors can play a substantial
role in inducing or possibly undermining technological activities. Section 2.4 reviews the main determinants that induce firms to perform technological activities and conversely identifies the main barriers to such activities. Among them, we can already mention technological opportunity, technological externalities or spillovers, demand pull factors, firm size, market structure and institutional factors. The economic and social effects of technological activities are manifold. For instance, the use, implementation or imitation of new products and processes by economic agents will have important consequences on several variables such as production costs, productivity, reallocation of inputs, profits, or competitiveness to name only a few of them. Before to conclude, we will discuss in Section 2.5 some of the most important outcomes of technological change.

2.2. FACTS ABOUT FIRMS’ TECHNOLOGICAL ACTIVITIES

In this section, we illustrate key facts on firms’ technological activities in industrially advanced countries. As we shall see, resources devoted to such activities have continuously increased and are still increasing in time. However, technological patterns are far from being similar across countries.

As a matter of fact, research and development (R&D) activities represent the most privileged method by which companies generate and acquire technological information. As it clearly appears from Figure 2.1, such activities account for a non negligible part of GDP. For both the United States and Japan the business-funded R&D as a percentage of GDP was about 1.9 in 1993. Germany follows closely with a ratio of 1.7. These leading countries are well above the OECD and the European Union averages which exhibit lower R&D to GDP ratio. A second outstanding fact emerging from Figure 2.1 is that resources devoted to R&D activities have been increasing over the eighties. While for the OECD countries, R&D to GDP has gained 0.2% from 1981 to 1993, this growing allocation of funds to R&D has been even higher for countries such as Japan, France, Canada or Italy.

9 In particular the role played by the firm’s accumulated knowledge capital on its productivity gains, the amount of this capital that spills out to other firms within an industry or across industries and countries, or the outcomes of firms’ technological activities as measured by patent applications.
Ch. II: Technological activities: determinants and outcomes

**Figure 2.1**
Trends in business-funded R&D as a percentage of GDP in 6 OECD countries: 1981 to 1993

![Graph showing trends in business-funded R&D as a percentage of GDP in 6 OECD countries: 1981 to 1993.](image)

source: OECD (1996a), Science and Technology Indicators

The personnel employed by firms in R&D is another widely used indicator of the importance of R&D activities. Figure 2.2 exhibit trends in business R&D personnel in five OECD countries over the period 1981 to 1992. While Japan appears to be the country with the highest number of researchers (583000 in 1992), it is at the same time the country which has experienced the highest annual average growth of this indicator, i.e. 4.4 % over the period against 2.2 % for France, Germany and Italy. In the United Kingdom, however, R&D personnel has declined by 1.8 % (in terms of annual average).

**Figure 2.2**

![Graph showing trends in business R&D personnel in 5 OECD countries: 1981 to 1992.](image)

source: OECD (1996a), Science and Technology Indicators
A common criticism addressed regarding these two indicators is that they measure the input of technological activities but not the output. Patent statistics, though they too are not exempt of any criticism, are on the other hand the most widely used measure of output of such activities. Figure 2.3 gives, for five major OECD countries and over the period 1981-1992, the main trends in inventiveness as measured by the logarithm of the number of resident patent applications per 10000 inhabitants. The high value of the inventiveness indicator for Japan must be interpreted *cum grano salis*. Indeed, the propensity to patent in Japan is typically higher than in any other country\(^\text{10}\). Despite this drawback, Japan is nevertheless the country with the highest rate of growth in inventiveness over the period.

![Figure 2.3](image)

Table 2.1 emphasizes the differences in technological profiles among the pillars of the Triad. Though total R&D outlays are quite comparable among the EU, the US and Japan, the effort devoted to R&D activities differ strongly between them. Indeed, in terms of total R&D expenditures per inhabitant, Japan comes first with 833 ECU’s. The US follows with 545 ECU’s long before the EU with only 329 ECU’s.

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\(^{10}\) The main reason being that Japanese inventors tend to file separate patents for each claim while US or European inventors gather their claims together in one patent.
Ch. II: Technological activities: determinants and outcomes

Table 2.1
R&D indicators for the Triad

<table>
<thead>
<tr>
<th></th>
<th>EU15</th>
<th>USA</th>
<th>JAPAN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total R&amp;D expenditures (MECU’s) 1994</strong></td>
<td>121882</td>
<td>142047</td>
<td>104069</td>
</tr>
<tr>
<td><strong>Total R&amp;D expenditures as % of GDP 1995</strong></td>
<td>1.91</td>
<td>2.45</td>
<td>2.95</td>
</tr>
<tr>
<td><strong>Total R&amp;D expenditures per inhabitant (ECU’s) 1994</strong></td>
<td>329</td>
<td>545</td>
<td>833</td>
</tr>
<tr>
<td><strong>% of total R&amp;D expenditures financed by governments 1993</strong></td>
<td>39.6</td>
<td>39.2</td>
<td>19.7</td>
</tr>
<tr>
<td><strong>Number of researchers 1993</strong></td>
<td>774071</td>
<td>962700</td>
<td>526501</td>
</tr>
<tr>
<td><strong>Number of researchers per thousand employed 1993</strong></td>
<td>4.7</td>
<td>7.4</td>
<td>8.0</td>
</tr>
<tr>
<td><strong>Number of researchers in industry 1993</strong></td>
<td>376000</td>
<td>765000</td>
<td>367000</td>
</tr>
<tr>
<td><strong>Number of researchers per thousand employed in industry 1993</strong></td>
<td>2</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

*source: European Commission (1996)*

In terms of the number of researchers per thousand employed, the ranking of the three pillars does not change. However, the difference between the US and Japan is less important. This may indicate that either the wages of Japanese R&D personnel are higher than in the US or either that the share of these expenses in total R&D expenditures are smaller. If we now turn to the number of researchers per thousand employed in industry, the gap between the EU and both the US and Japan is more significant. This result is a consequence of the larger number of European researchers outside the industry sector, i.e. universities as well as public research centers.

Table 2.2 displays the 20 most important worldwide companies in terms of R&D expenditures\(^{11}\). The biggest R&D spender in 1994 was General Motors with 6.3 billions $ which represent more than four times the R&D budget of Volkswagen, the last firm in Table 2.2. The ranking of the top 20 R&D firms is dominated by electronics, although the first three companies are in the automotive industry. Finally, if we compare the ranking of 1994 with the ranking of 1986, only 11 firms out of 20 still figure in the top 20 ranking. This observation shows the importance of the dynamics associated with R&D activities. The same conclusion can be drawn with regard to the annual average R&D growth rate of the same firms. As far as output is concerned, there seems to be even more dynamism, since, as shown in the last two columns of Table2.2, when firms are ranked by sales instead of R&D, the ranks change more often.

\(^{11}\) These firms come from the LITE database whose construction and main properties are discussed in Chapter 3.
### Table 2.2
Top 20 (out of 2445) R&D firms in the LITE database, 1994

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GENERAL MOTORS</td>
<td>USA</td>
<td>3711</td>
<td>AUTOMOTIVE</td>
<td>6321</td>
<td>3.3</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>FORD MOTOR</td>
<td>USA</td>
<td>3711</td>
<td>AUTOMOTIVE</td>
<td>4685</td>
<td>8.2</td>
<td>4</td>
<td>35</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>DAIMLER-BENZ</td>
<td>Germany</td>
<td>3711</td>
<td>AUTOMOTIVE</td>
<td>4574</td>
<td>28.5</td>
<td>16</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>SIEMENS</td>
<td>Germany</td>
<td>1731</td>
<td>ELECTRICAL</td>
<td>3951</td>
<td>0.9</td>
<td>3</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>IBM</td>
<td>USA</td>
<td>3570</td>
<td>ELECTRONICS</td>
<td>3920</td>
<td>-4.0</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>HITACHI</td>
<td>Japan</td>
<td>3570</td>
<td>ELECTRONICS</td>
<td>3200 na</td>
<td>na</td>
<td>na</td>
<td>7</td>
<td>na</td>
</tr>
<tr>
<td>7</td>
<td>MATSUSHITA ELECTRIC</td>
<td>Japan</td>
<td>3651</td>
<td>ELECTRONICS</td>
<td>2523 na</td>
<td>na</td>
<td>na</td>
<td>12</td>
<td>na</td>
</tr>
<tr>
<td>8</td>
<td>TOSHIBA</td>
<td>Japan</td>
<td>3570</td>
<td>ELECTRONICS</td>
<td>2058</td>
<td>5.5</td>
<td>13</td>
<td>20</td>
<td>21</td>
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<tr>
<td>9</td>
<td>NEC</td>
<td>Japan</td>
<td>3570</td>
<td>ELECTRONICS</td>
<td>1998</td>
<td>-1.7</td>
<td>6</td>
<td>29</td>
<td>30</td>
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<tr>
<td>10</td>
<td>ERICSSON</td>
<td>Sweden</td>
<td>3663</td>
<td>ELECTRONICS</td>
<td>1969</td>
<td>20.6</td>
<td>39</td>
<td>66</td>
<td>86</td>
</tr>
<tr>
<td>11</td>
<td>PHILIPS ELECTRONICS</td>
<td>Netherlands</td>
<td>3650</td>
<td>ELECTRONICS</td>
<td>1870</td>
<td>-2.4</td>
<td>5</td>
<td>19</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>ALCATEL ALSTHOM</td>
<td>France</td>
<td>3669</td>
<td>ELECTRONICS</td>
<td>1824</td>
<td>6.8</td>
<td>20</td>
<td>23</td>
<td>28</td>
</tr>
<tr>
<td>13</td>
<td>HEWLETT-PACKARD</td>
<td>USA</td>
<td>3571</td>
<td>ELECTRONICS</td>
<td>1821</td>
<td>9.9</td>
<td>26</td>
<td>33</td>
<td>67</td>
</tr>
<tr>
<td>14</td>
<td>HOECHST</td>
<td>Germany</td>
<td>2834</td>
<td>CHEMICALS</td>
<td>1773</td>
<td>2.3</td>
<td>9</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td>15</td>
<td>BAYER</td>
<td>Germany</td>
<td>2834</td>
<td>CHEMICALS</td>
<td>1672</td>
<td>2.2</td>
<td>12</td>
<td>32</td>
<td>13</td>
</tr>
<tr>
<td>16</td>
<td>MOTOROLA</td>
<td>USA</td>
<td>3650</td>
<td>ELECTRONICS</td>
<td>1671</td>
<td>21.2</td>
<td>52</td>
<td>38</td>
<td>91</td>
</tr>
<tr>
<td>17</td>
<td>BOEING</td>
<td>USA</td>
<td>3721</td>
<td>AEROSPACE</td>
<td>1531</td>
<td>8.1</td>
<td>30</td>
<td>39</td>
<td>25</td>
</tr>
<tr>
<td>18</td>
<td>SONY</td>
<td>Japan</td>
<td>3651</td>
<td>ELECTRONICS</td>
<td>1519</td>
<td>8.2</td>
<td>31</td>
<td>28</td>
<td>56</td>
</tr>
<tr>
<td>19</td>
<td>ROCHE</td>
<td>Switzerland</td>
<td>2834</td>
<td>DRUGS</td>
<td>1499</td>
<td>6.7</td>
<td>28</td>
<td>85</td>
<td>95</td>
</tr>
<tr>
<td>20</td>
<td>VOLKSWAGEN</td>
<td>Germany</td>
<td>3711</td>
<td>AUTOMOTIVE</td>
<td>1473</td>
<td>2.4</td>
<td>18</td>
<td>14</td>
<td>8</td>
</tr>
</tbody>
</table>

*source*: Worldscope database (1995) and own calculations

*note*: a) million 1990 $, deflated by country specific GDP deflators

b) annual average 1986-1994

### 2.3. TECHNOLOGICAL CHANGE: CONCEPTS AND DEFINITIONS

This section defines basic concepts such as technological change, change of techniques, invention, innovation, product and process innovation. These concepts will be used throughout the thesis and need to be analyzed in some detail.

#### 2.3.1. Process of Technological change

First of all, let us define the concept of technological change. According to Stoneman (1983), the concept of technological change encompasses improvements in products, production processes, material and intermediate inputs, and management methods in the economic system. The notion of change of techniques is close to the one of technological change. However, the distinction between these two notions appears to be ambiguous and
Mansfield (1968) defines technology as the whole set of (technical or managerial) knowledge which enables to launch new products or processes. Techniques differ from technology in so far as, the former is a production method at a given time which is defined by the equipment and management methods used, while the latter encompasses the whole set of knowledge used in the production. The term ‘technique’ can be reserved for productive equipment and the work organization they involve. Technology is a more comprehensive concept that incorporates other functions such as management and control which are grafted on to the technique. In Schmookler’s view (1966: p.2), technique is also viewed as a method of producing a given good or service and technical change arise when “an enterprise produces a good or service or uses a method or input that is new to it”.

Following the traditional schumpeterian thought, it is common to divide the technological change process into three stages: invention, innovation and diffusion. The first stage, the invention process, corresponds to the generation of new ideas, e.g. a new product, process or system. Freeman (1982) defines an invention as “an idea, a sketch or model for a new improved device, product process or system. Such inventions may often (not always) be patented but they do not necessarily lead to technical innovation”. Kennedy and Thirwall (1972) view inventing as imagining new ways of attaining the same objective. Therefore, the inventing activity encompasses not only the creation (thanks to the use of existent and ‘new’ knowledge) of previously non-existent products, processes, and systems, but also an original exploitation of elements that have always existed.

The innovation process is the second stage of technological change. Quoting Freeman (1982), “an innovation, in the economic sense, is accomplished only with the first commercial transaction involving the new product, process, system or device although the word is used also to describe the whole process”. Hence, during this stage, new ideas are developed into marketable products and processes. Schumpeter (1942) distinguishes five main types of innovation: product innovation, process innovation, new markets and marketing methods, legislation changes and innovations with regard to organization. Product innovation relates to R&D aimed at improving, creating, introducing or diffusing new products (with the production process being unchanged) while process innovation is referred to as R&D activities directed towards perfecting the methods or obtaining new processes. Process innovations generally reduce the cost of producing a generally unchanged product. However, both kinds of
innovations very often go hand-by-hand. Furthermore, as pointed out by Kuznets (1971), an innovation may constitute a product innovation from the point of view of the firm that produces it and it may be a process innovation for the firm using it\textsuperscript{12}.

During the final \textit{diffusion} stage, new products and processes spread across the potential market. According to Vickery and Blair (1987), the speed at which new technologies diffuse and are applied in the manufacturing industry as well as the direction in which this process propagates, play a determining role in economic growth and competitiveness. Among the factors that influence the diffusion process, one has to distinguish between macro and micro economic factors. At the macro level, the global demand, the level of prices, the international competitiveness, the balance of payments (to the extent that it favors export), employment and the global behavior of the labor markets are the key determinants that are likely to induce diffusion of technologies. Among the factors at the micro level, the authors bring to the fore the sectorial distribution of firms, their size, their sensibility to new technologies, the existence of a skilled personnel, the technical problems raised by applying new technologies, the sources and the costs of financing it, the environment and technological infrastructure. In addition to the market structure, the speed at which the diffusion process occurs is likely to vary according to whether a new technology spreads across firms belonging to different industries (inter-industry diffusion) or firms within the same industrial sector (intra-industry diffusion). The same distinction can be made for firms in different countries (international diffusion) or located within the boundaries of any given country (intra-national diffusion).

The diffusion process is closely linked to the time profile of technological change and new technologies usually take a considerable period of time to diffuse. Quoting Karshenas and Stoneman (1995: p.265), “whether it be a new consumer technology spreading across households or a new producer (process) technology spreading across firms, it would not be unusual for the time period between first use of a technology and say 90 percent of that technology to take several decades rather several years”.

The authors continue by emphasizing that “the measured time periods involved do, however, depend on what we consider to be a technology”. This argument introduces the notion of

\textsuperscript{12} “Thus, the Bessemer converter was a process innovation to iron and steel manufacturers but a product
generic (or drastic) versus minor (or incremental) innovations. An \textit{incremental innovation}\ refers to the small and continuous improvements and/or further developments which follow a major or \textit{drastic innovation}. For instance the discovery of the Bessemer converter in the second-half of the nineteenth century can be viewed as a generic innovation which led to the development of several minor 'post-Bessemer' innovations in iron and steel\textsuperscript{13}.

Another common distinction regarding technological innovation is the one between global and local innovations. A \textit{global innovation} is often referred to as being the first occurrence in an economy (launching of a new product for instance), while a \textit{local innovation} is also concerned with the introduction of a new innovation but in the unit of observation, e.g. a firm. For instance the launching of Intel’s Pentium new processor can be seen as a local innovation although many other computer’s processors have been previously introduced by other manufacturers.

Finally, it should be noted that the threefold process of technological change is not linear (Kline and Rosenberg, 1986). Each stage is characterized by a selection process: only certain new ideas are developed through the market and only some of the innovations are successfully diffused. Moreover, there are extensive feedbacks from one stage to the other and it is hard to adequately represent the whole process of technological change by a linear process. These feedback effects have to be considered when characterizing the time profile of technological change.

\textbf{2.3.2. Scope of R&D activities}

Research and development is commonly thought as being the main source of technological change. Actually, scientific, technological, organizational, financial or commercial activities play an important part in the process of technological change as well.

Before reviewing these activities, let us give the definition of research and development as presented by the OECD Frascati’s manual (1993: p.29): “\textit{experimental research and development encompasses any creative works systematically undertaken in order to increase the innovation to the suppliers of equipment to the iron and steel industry}”, Rosenberg (1983: p.4).
knowledge stock, including the knowledge of mankind, culture and society as well as the use of it to achieve new applications”. R&D is usually organized in three activities: fundamental research, applied research and development.

Fundamental research consists in experimental or theoretical works aimed at acquiring further knowledge about the foundations of observable phenomena and facts, without considering any particular application or utilization. The expected result is discovery. Fundamental research comes close to the notion of basic research which can be defined as research activities undertaken with no particular applied objective in view. Hence, most scientific research activities as well as the research performed by universities or public institutes are considered as basic research. In terms of the three stages of the technological change process, basic research would be more related to the invention stage.

Applied research also consists in experimental works which are mainly undertaken in order to acquire further knowledge. However, applied research departs from fundamental research in so far as the former is directed towards a specific objective or particular goal. Applied research is more likely to take place in the commercial sector and it corresponds to the innovation stage of technological change.

As pointed out by Capron (1993), fundamental and applied researches only have economic implications if they have a cost or if, in the short term, they allow a commercial exploitation.

Development is concerned with systematic work based on existent knowledge obtained through research and/or practical experience, with a view of:

- launching the production of new materials, products or devices,
- establishing new processes, systems or services, or,
- improving those that already exist.

The expected result is information and innovation through investment and experience. Finally, in order to bring out the strategic elements associated with research activities, both basic or fundamental and applied research can be split into subcategories: pure and oriented

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13 These innovations “continued to emphasize not only greater fuel efficiency but also continual widening of
fundamental research, on the one hand, and general oriented and specific applied research, on the other hand.

**Pure fundamental research** is carried out with the view of making knowledge progress without working for long-term economic or social benefits, and with no deliberate efforts being made to apply the outcomes of this research towards practical issues, or for transferring the results towards sectors in charge of their application. **Oriented fundamental research** is undertaken with the hope that it will result in setting up a large knowledge base allowing to solve problems or to give concrete expression to current or future opportunities. **General oriented applied research** consists in original works undertaken with the view of acquiring new knowledge which has not yet reached the phase in which it is possible to clearly define what would be *in fine* its application or practical determined objective. **Specific applied research** is referred to as original works undertaken in order to acquire new knowledge centered on a determined goal or practical objective whose applications are clearly and already known.

R&D is not the only mean for acquiring new knowledge and generating new technologies. Firms engaged in innovative activities have, at their disposal, learning of various kinds to implement them. R&D only includes some of these learning processes. For instance, preliminary results from the Community Innovation Survey (CIS), reported in Figure 2.4, indicate that though R&D expenditures represent the largest share in firms’ total innovation expenses, other ‘activities’ such as testing, product design, market analysis or costs for granting patents are also important ingredients of such expenses.

Besides these ‘activities’ of learning about new processes and methods, other ‘channels’ for acquiring and using external knowledge should also be mentioned. Among them, we may cite activities such as reverse engineering\(^{14}\), closely examining patent disclosures or scientific publications, attending public presentation of various types, e.g. technical meetings, fairs, exhibitions, or conferences, and hiring or having consultations with employees from innovating firms. For instance, firms may increase their technological knowledge through *the range of usable inputs and more precise quality control in the final output.*” Rosenberg (1983: p.91).

\(^{14}\) Reverse engineering is defined as a systematic approach for analyzing the design of existing devices or systems (Turner, 1996). This activity is generally split up into three stages:

- observe and make guesses about the mechanisms that make device work,
- dissect and study the inner workings of a mechanical device and
- compare actual device to guesses and suggest improvements.
imitation or reverse engineering by purchasing capital goods from other firms in different industries or countries. Firms may also generate technological advance through licensing agreements or R&D collaborative agreements via joint ventures for instance. **Precompetitive research**, for instance, is focused on generic long-term research of interest to all member companies of a joint venture. In a similar vein, rather than in-house activities, problem solving analysis or technical assistance to any R&D project may be performed by any organization external to the firm, e.g. consultants, universities or subcontractors. Finally, quoting Dosi (1988: p.1124), “a significant amount of innovation and improvement is originated through design improvements, ‘learning by doing’, and ‘learning by using’. Such informal effort is generally embodied in people and organizations (primarily firms), and its cost is hard to trace”.

**Figure 2.4**

**Distribution of Innovation Expenses in 1992 in some Member States**

![Pie chart showing distribution of innovation expenses in 1992](image)

*source*: EUROSTAT (1996), Community Innovation Survey, Preliminary results

*note*: *Belgium, Denmark, Germany, Ireland, Italy, Luxembourg, Netherlands and Spain, 1992.

Table 2.3 summarizes the main results obtained by Levin et al. (1987) with their survey on the effectiveness of alternative methods of learning about new processes and methods. Among these learning methods, independent R&D appears to be the most important one. Indeed, the absorption of outside technologies requires technological competencies which can only be developed through own R&D. Besides independent R&D, licensing and reverse engineering are two other important methods for making use of technologies developed by others.
Table 2.3
Effectiveness of alternative methods of learning about new processes and products\(^a\)

<table>
<thead>
<tr>
<th>Method of learning</th>
<th>Processes</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Licensing technology</td>
<td>4.6 (.07)</td>
<td>4.6 (.07)</td>
</tr>
<tr>
<td>Patent disclosures</td>
<td>3.9 (.05)</td>
<td>4.0 (.06)</td>
</tr>
<tr>
<td>Publications or technical meetings</td>
<td>4.1 (.05)</td>
<td>4.1 (.05)</td>
</tr>
<tr>
<td>Conversations with employees of innovating firm</td>
<td>3.6 (.06)</td>
<td>3.6 (.06)</td>
</tr>
<tr>
<td>Hiring R&amp;D employees from innovating firm</td>
<td>4.0 (.07)</td>
<td>4.1 (.07)</td>
</tr>
<tr>
<td>Reverse engineering of product</td>
<td>4.1 (.07)</td>
<td>4.8 (.06)</td>
</tr>
<tr>
<td>Independent R&amp;D</td>
<td>4.8 (.06)</td>
<td>5.0 (.05)</td>
</tr>
</tbody>
</table>

*Source:* Levin et al. (1987)

*Note:* a) questionnaire sent to 650 industrial R&D directors representing 130 lines of business in the US.

The process of technological change involves the commitment of different sources of capital to finance it\(^{15}\). It is generally common to distinguish between *business-funded research* and *public-financed research* activities. Table 2.4 (taken from Mowery, 1995) points out the diversity of patterns regarding the public funds that finance R&D. It can be observed that these percentages vary to a great extent across industries. Generally, the percentage of government-funded R&D is much higher in aerospace, electronic engineering and the industry sectors related to defense or military activities. Indeed, the importance of defense related R&D in the US, UK and France may explain the high share of public-financed R&D performed in industry in these countries, “*since such R&D frequently is funded as a part of procurement contracts with private firms*”\(^{16}\).

The intervention of governments in the financing of R&D activities can take several forms. A first distinction has to be made according to whether the intervention concerns public actors such as universities or public research centers, or whether it is aimed at supporting private R&D. Among the channels by which public funds are distributed, the most common are subsidies and fiscal incentives to R&D investment. Subsidies can take the shape of fixed amounts granted at project start and loans. Sometimes, loans are conditional to the extent that they are repaid only if the project is profitable. Fiscal incentives such as favorable tax treatments typically apply to business firms.

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\(^{15}\) See for instance Adam and Farber (1994).

\(^{16}\) Mowery (1995: p. 519)
The funds engaged by firms to undertake their R&D activities may be generated internally or may come from outside the firm. **Internal financing** is referred to internally generated funds; for the most part, these are retained profits but also sometimes the access to common funds generated by joint ventures or co-operative agreements. Two main sources of **external financing** are debt and equity. Although, the shares of internal and external resources to R&D vary across firms, industries and countries, it is generally admitted that on average, internal financing accounts for more than 90% of total private resources allocated to finance R&D.

<table>
<thead>
<tr>
<th>Government share of national R&amp;D performed in industry (%)</th>
<th>Share of total government funded R&amp;D performed in public labs (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA 35</td>
<td>12</td>
</tr>
<tr>
<td>Germany 12</td>
<td>33</td>
</tr>
<tr>
<td>UK 27</td>
<td>16</td>
</tr>
<tr>
<td>France 38</td>
<td>27</td>
</tr>
<tr>
<td>Japan 2</td>
<td>na</td>
</tr>
</tbody>
</table>


### 2.4. DETERMINANTS OF TECHNOLOGICAL CHANGE

It is obvious that the underlying process that characterizes technological change is a complex one. The rate of technological change is determined by various factors, and R&D is considered to be one of the most important. The purpose of this section is to provide a review of the most prominent determinants, other than R&D, that influence the magnitudes and patterns of technological activities carried out by firms. By way of introduction, some of these determinants that firms consider as the most significant are illustrated.

Why do firms allocate resources in R&D? Profit incentives and increased market share are two main motivating forces behind R&D. For instance, according to the head of R&D at Hoechst, “the aim of R&D is to add value continually” and “the key criterion is the future profit of
the group”17. Figures 2.5 and 2.6 shed some light on the main factors that incite firms to engage in innovative activities as well as the main barriers to such activities. Figure 2.5 indicates that the essential objectives of innovation are of a competitive nature.

Figure 2.5
Importance of the objectives of Innovation (Percentage of firms considering these factors as very important or essential (1990-1992))

![Graph showing the importance of objectives of innovation](image)

Source: EUROSTAT (1996), Community Innovation Survey, Preliminary results

At the other end, Figure 2.6 shows that the economic environment, firm specific factors and the intellectual property rights system appear to be the three main determinants hampering innovation.

What do we mean by ‘competitive nature’, ‘economic environment’ or ‘firm linked factors’? The reminder of this section tries to give some pieces of answers. But before we proceed, it is worth reminding the main features that characterize knowledge viewed as an economic good.

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17 See Appendix A.2.1.
2.4.1. Knowledge production and market failures

Why do governments intervene in the financing of private activities? One fundamental characteristic that differentiates R&D activities from other economic activities is the uncertainty and risks inherent to it. These uncertainties play a fundamental role in the allocation of resources to innovate. In his seminal paper, Arrow (1962: p.609) wrote: “from the viewpoint of welfare economics, the determination of optimal resource allocation for invention will depend on the technological characteristics of the invention process and the nature of the market for knowledge”. Arrow showed why the three generic sources of possible failure of perfect competition to achieve Pareto-optimality in resource allocation\(^\text{18}\), hold in the case of knowledge generating activities.

First, because of the time it takes to succeed, a typical R&D project involves important fixed set-up costs. Hence R&D activities should be viewed mainly as a fixed factor of production and consequently, they require economies of scale to be written off the original costs. This ‘\textit{indivisible}’ aspect of R&D as an input causes non-convexities in the production functions and imply that the marginal costs are under the average costs, a situation which is not

\(^{18}\) e.g. indivisibilities, uncertainties and externalities.
Ch. II: Technological activities: determinants and outcomes

viable under perfect competition. Second, R&D activities are inherently risky. These technological uncertainties add to the ‘commercial’ risk of successfully selling a product on the final market of goods and services and lead firms to choose to produce or invest ‘too little’ in R&D. Moreover, besides the ‘pure’ technological difficulty of any R&D project, its probability to succeed also depends on the amount of effort undertaken by researchers which is difficult if not impossible to perceive. This raises a moral hazard issue since agents mostly are unable to shift the risks intrinsic to R&D projects. Third, the public goods feature of knowledge generates externalities or technological spillovers. The theory of optimal resource allocation under the presence of externalities has been studied through the divergence between social and private returns (or costs) of the production process. In the case of knowledge, this wedge arises because of the non rival and partially excludable property of knowledge which distinguishes it from other strategic activities undertaken by firms. Non rivalry means that the use of an innovation by an agent does not preclude others to use it, while partially excludability implies that the owner of an innovation can not impede others to benefit from it free of charge. Because of this, the rate of return from an innovation is lesser and as a result, the incentives for carrying out R&D are reduced.

It has just been argued that, because of the partial public aspect of knowledge, firms that undertake technological activities cannot exclude others from obtaining a part of the benefits free of charge. Hence, these externalities or technological spillovers occur because the benefits derived from R&D activities are not entirely appropriable. Actually, as stressed by Griliches (1979), there is often a confusion about the two distinct notions of technological spillovers. The first kind of spillovers is related to new products and processes which embody technological change and are bought by other firms at less than their ‘full quality adjusted’ prices. The second kind of technological spillovers can be defined as the potential benefits of the research activity of other firms for a given firm. As pointed out by Geroski (1995), knowledge spillovers are basically externalities that flow between ‘adjacent’ producers and/or users of an innovation. To measure their size, one needs to decide which producers or users are ‘adjacent’ to each other. Hence, a distinction can be made between the spillovers emanating from the firm’s industry and those generated by other industries. According to the

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19 At the opposite, according to Nelson (1959), each firm will try to benefit or to free ride as much as possible from the public stock of knowledge without having to finance it.

20 The empirical formalization of this concept of ‘distance’ is the purpose of Chapter 6.
In order to assess the impact and the size of technological spillovers, one needs to focus on some observable measures of performance which are likely to be affected by such phenomena. One of these variables are the costs required to undertake innovation. Indeed, if the appropriability of knowledge is imperfect and if many firms are involved in similar technological activities, then the costs of innovation for a given firm are likely to be affected by these activities. For instance, if the technological spillovers and the firm’s own R&D are complementary, then an increase of these spillovers should lead the firm to intensify its R&D effort. In turn, this intensification of the R&D effort should be reflected in the number of patents the firms applies for. Another variable likely to be affected is total factor productivity. If productivity performances are associated with investment in the improvement of technology, than these improvements should be affected not only by the firm’s own R&D activities but also by the pool of general knowledge accessible to it. In other words, the R&D activities that spill over to a firm affect its productivity performances. Also, if R&D intensive inputs are purchased from other firms at less than their full quality adjusted price, then these quality improvements, to the extent that they are imperfectly, if at all, incorporated in official prices indexes, should be translated into lower productivity effects.

Finally, it should be noted that because of lags in the diffusion of knowledge, spillover effects are probably not contemporaneous. That is, the time it takes for these effects to concretize into new products and processes and result in productivity performance, may actually be quite long.

If flows of knowledge among users and producers of innovation are observed in the economy, then the outcomes of R&D activities are not entirely appropriable. This appropriability issue arises when the costs of transmitting technology are not very high\textsuperscript{21}. Several factors can be expected to affect these costs: the nature of technology, i.e. its complexity, its rate of change and the degree to which it is related to the firm and experience,

\textsuperscript{21} According to Geroski (1995), technological transfers are rarely costless: in order to be able to benefit from an innovation, agents have to be well informed about its technological content. This information has often a cost. Hence to benefit from technology transfers, agents typically will have to invest themselves in R&D.
the legal and institutional characteristics of markets, and the internal capabilities of the innovator.

2.4.2. Role of firm and industry characteristics upon innovation

The main argument put forward by equilibrium models of market structure is the fact that the smaller the number of firms in an industry, the more influence those firms have over price and the less efficient they will be in terms of output. The main contribution of Schumpeter in his work *Capitalism, Socialism and Democracy* (1942), was to show that a theory including innovations leads to different conclusions from those of equilibrium models. Schumpeter argues that for firms engaged in innovative activities, conditions of imperfect competition can sometimes be necessary and more efficient than perfect competition, especially in the long run. Following this assertion, two hypotheses have been intensively investigated in the literature: innovation increases more than proportionally with firm size, and innovation increases with market size.

Several arguments for a positive effect of firm size on innovation have been suggested. First, the imperfections associated with capital markets give an advantage to large firms in securing finance for risky R&D projects to the extent that availability and stability of internally generated funds are higher. Second, to the extent that economies of scale and of scope are important in R&D activities, the returns from R&D will be higher for large and diversified firms. For instance, large volume of sales and complementarities between R&D and other manufacturing activities, e.g. marketing and financial planning, allow to further spread the fixed costs of innovation. Still, counter-arguments to firm size have been put forward. The first one is the loss of managerial control or conversely the excess of bureaucratic control associated with firm size. A second counter-argument is the lesser incentives of the R&D personnel because of the lesser appropriability of individual effort and ‘frustration of hierarchies’.

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22 In Schumpeter’s view, the atomistic firm operating in a competitive market may be a perfectly suitable vehicle for static resource allocation, but the large firm operating in a concentrated market was the “most powerful engine of progress and ... long-run expansion of total output”. In this respect “perfect competition is inferior, and has no title to being set up as a model of ideal efficiency”. Schumpeter (1942: p.106). Taken from Cohen and Levin (1989: p.1060).
Regarding the effects of market concentration on innovation, Schumpeter advances three arguments. First, the incentive to invent is associated with expected ex-post market power. Second, ex-ante market power reduces the uncertainty associated with excessive rivalry, and third, the profits generated by ex-ante market power provide internal financial resources which can be allocated to innovative activities without calling on outside financing\textsuperscript{24}.

Besides firm size and market power, other relevant firm’s characteristics explaining the incentive to undertake R&D have been examined in the literature. One of these characteristics is the firm’s cash-flow which represents a measure of a firm internal financial capability. The main reason for examining cash-flow as a determinant of R&D effort is based largely on the argument that in a world of capital market imperfections, large firms are favored by available internal funds.

Another firm characteristic which has often been investigated is the diversity of the firm’s activities. This determinant finds its origin in Nelson’s argument (1959) according to which, the unpredictable nature of the results of research activities implies that the diversified firm possesses more opportunities for exploiting the new knowledge or is better positioned to exploit complementarities between its various activities.

The last factor explaining the level of effort devoted by firms to innovative activities is their specific capabilities to link product development and upstream applied research. Such capabilities are associated with the firm’s internal organization and information processing as well as the composition and the nature of R&D, e.g. basic or applied research, process or product research, incremental or generic innovation.

In addition to these firm’s specific characteristics, three kinds of conditions that affect interindustry variations in innovative activity and performance have been identified. These conditions are: the demand an innovator faces in the market of final goods, the technological opportunity and the conditions in appropriating the results of his innovations. These conditions are more likely to differ across industries and technological areas of research activities and be more or less constant within a given industry.

\textsuperscript{23} See Cohen and Levin (1989) for a review.
\textsuperscript{24} Because of capital market imperfections, it is not obvious that these resources could have been obtained from outside the firm at least at the same cost.
Schmookler (1954, 1966) has emphasized the role of ‘demand pull’ forces behind technological change. These determinants correspond to the market factors attracting and influencing innovation. According to Schmookler, the rate and direction of technological change is the outcome of profit seeking firms and as a consequence of the demand. Among the main interindustry differences of demand conditions which affect the incentives to engage in innovative activities, a distinction can be made between the size of the market goods, and the price elasticity of demand. Hence, for Kamien and Schwartz (1970), the gains from reducing the costs of production, in the case of a process innovation, are larger the more elastic the demand is. On the contrary, according to Spence (1975), the gains from improvements in product quality, in the case of a product innovation, are larger the more inelastic the demand is (inelastic demand tends to magnify the gains from a rightward shift in the demand curve). It should be noted that the overall effect of price elasticity is ambiguous since, very often, no distinction is made between product and process R&D.

Rather than as exogenous, the market structure and the conditions characterizing it should be viewed as an evolutionary process. For example, the launching of a new innovation in an industry is likely to have some kind of repercussion on the firms’ behavior. For instance, a firm adopting an innovation which consists of a semi-processed product will reallocate its inputs. Also, because of this adoption, the profits, the market share and the price of the final good are likely to vary. These changes will be transmitted to the firm’s upstream suppliers, as well as to its downstream customers. The demand of the new good may intensify to the detriment of the previous inputs because of their lesser efficiency or even because of their obsolescence. The launching of a new drastic innovation in an industrial sector often leads to the development of several innovations of lesser importance. The reasons which motivate the development of such ‘incremental’ innovations may be the consequence of new needs from the consumers generated by the generic innovation.

It would be a truism to say that technical advance, at prevailing input prices, is ‘easier’, i.e. less costly in some industries than in others. These difficulties or costs associated with the innovative activity in any field of technological specialization can be apprehended under the notion of technological opportunity. Two main reasons can be put forward to explain why

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25 See also Nelson and Winter (1977), Mowery and Rosenberg (1979).
26 “Entrepreneurs incessantly revolutionize the economic structure from within, incessantly destroying the old one, incessantly creating a new one, a process of ‘creative destruction’”. Schumpeter (1942: p. 83).
these costs may vary according to technological fields: the characteristics intrinsic to
technology, and the available stock of scientific knowledge at a certain point of time\(^27\). Both
differ across fields of technological specializations. Because of these characteristics, it might be
more difficult for instance, to make a drastic discovery in the field of thermonuclear fusion than
in the field related to the aerodynamic shape of motor vehicles. These differences are assumed
to be reflected by technological opportunities which vary from a technological class to another
and which makes the technological activity of a given firm more profitable in some fields.
Technological opportunity and appropriability have often been designated as ‘technology push
forces’ (Rosenberg, 1983). These exogenous factors from the supply side of innovation ‘push’
the innovative activities bringing pressures on such activities.

2.4.3. Rivalry and strategic technological competition

A significant part of the recent literature on the theory of industrial organization has
been concerned with a better analytical understanding of strategic behaviors adopted by firms
engaged in R&D activities. Three incentives that determine the resources allocated to R&D are
at the core of the recent interest devoted by economists to these questions (Cohen and
Levinthal, 1989). First, firms may undertake R&D activities to enhance their profit by pursuing
new product and process innovation (profit incentive) and second, to enhance their market
share (strategic advantage over their rivals). Indeed, if a firm knows that its rivals are
engaging in R&D, it will see its own competitive position as being under threat (competitive
threat). In a same vein, a firm failing to maintain a current position and being replaced by a
rival will suffer a loss (replacement effect). A monopolist does not fear to be replaced by a
rival and therefore, there is no strategic threat. A third incentive for a firm to engage in R&D
consists in developing and maintaining its broader capabilities to assimilate and exploit
externally available innovation.

Behavioral models under oligopolistic market environments have been developed in
economic theory. Rather than competing by price changes, oligopolistic firms prefer to turn to
product differentiation and quality improvements in order to preserve their market share. In
industries characterized by a high R&D intensity, technology is a main component of the non-

\(^27\) Mowery and Rosenberg (1979) attach a crucial importance to scientific discoveries in the process of
technological innovation.
price competition. As pointed out by Cohen (1995), the empirical literature on technological strategic interactions remains a largely neglected issue. Indeed, there is an astonishing gap between the abundance of theoretical models of R&D rivalry and the lack of real empirical examination of the extent of R&D competition. Yet, the first theoretical arguments developed by Scherer (1967) showed that the increase of R&D efforts of a firm will generally stimulate R&D expenditures of competitors.

In the eighties, game-theoretic models of R&D rivalry rejuvenated the question of the role of strategic interactions. As shown by these models, the competitive threat resulting from higher engagements of rivals in R&D is a key determinant to explain the amount of resources allocated to R&D by a firm. However, the limited empirical evidence on technological strategic interactions does not allow one to conclude whether this point really matters.

2.4.4. Public S&T policies and technological change

Up to now, we have shown that some determinants have a positive impact on innovative activities while others appear to undermine these activities. Hence, when engaging in innovative activities, firms and other private or public research institutions may wish to find ways of favoring determinants having positive effects on innovation and conversely, they may want to minimize the effects of those determinants weakening the incentives to undertake technological activities. Besides these measures taken by private or public actors engaged in innovative activities, public authorities may play another important role in pursuing policies that enhance, promote and support innovative and economic performances.

Indeed, for a long time, activities aimed at increasing the stock of knowledge have been neglected by policy-makers. Yet, after the sudden adjustment of oil prices in the early 1970’s and the worsening of the economic situation that followed, it became clear that both physical

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28 See Reinganum (1989) and Beath, Katsoulakos and Ulph (1995) for a review of this literature.
29 Quoting Cohen (1995: p. 234), “The challenges confronting the analysis of the role of strategic interaction are considerable. First, the recent game-theoretic models of R&D rivalry do not provide clear, testable empirical implications partly because they analyse behaviour in highly stylised and counterfactual settings. For example, many models focus on the interaction of a single incumbent and a single prospective entrant, or, alternatively, symmetric competitors. Moreover, many of the results obtained in this literature, ... depend upon typically unverifiable assumptions concerning the distribution of information, the identity of the decision variables, and the sequences of moves.” Yet, in a recent empirical paper which explores racing behaviour in
and human knowledge capitals were in reality at the root of economic growth and welfare. Policy-makers realized that those nations that will excel at creating new knowledge and transforming it into new technologies, products and processes will also have a higher chance in increasing their welfare. This has led to a greater policy attention paid to processes of technological activities.

Four main axes of policies that favor innovation may be distinguished:

- policies that overcome the failures associated with market of knowledge, i.e. appropriability, uncertainties and indivisibilities;
- technology policies on the supply side of innovation;
- technology policies that encourage the ‘adoption’ of innovations;
- competition policies.

The final part of this section gives a brief outline of the main ideas behind some of these S&T policies.

As it has already been discussed, the imperfect appropriability of innovative outcomes creates a wedge between the private and social returns to R&D. In order to reduce this wedge, several public policies can be implemented. The first kind of policies can be related to measures aimed at rising the expected returns by lowering the costs of doing R&D. Among these measures, direct or indirect subsidies as well as measures that facilitate the exploitation of economies of scale can be mentioned. Another way to reduce the gap between private and social returns to R&D consists in directly or indirectly restricting the exploitation of knowledge. Protection through patents or trade marks is referred to as a direct restriction to such exploitation. Measures favoring the internalization of externalities generated by R&D activities as well as vertical strategies developed by innovative firms, are said to be indirect restrictions.

Subsidies implemented to increase the private returns to R&D can take several forms. The two most common are tax credits based on total R&D expenditures and levy/grant systems, i.e. lump sum taxes. As pointed out by Spence (1984), subsidies have added benefits: they lower entry barriers, increase competition, lower margins and improve allocative efficiency. However, subsidies are not easy to implement because they require from the policy

the disk drive industry, Lerner (1997) concludes that the greatest innovative activity is observed by firms that are close to the leader.
maker an assessment of the wedge between private and social return to R&D. Moreover these gaps are likely to vary tremendously across industries if not from one country or geographic area to the other. In addition, subsidies may actually reward creative accounting practices or encourage firms to undertake second rate R&D projects that have little commercial promise (Stoneman, 1987).

A second type of policy aimed at reducing the costs of doing R&D and consequently at increasing the returns to this activity, consists in adopting measures in order to restructure a firm or an industry with the view of facilitating the exploitation of economies of scale in R&D. Indeed, such scale economies should help firms to reduce their fixed costs and moderate the issue of indivisibilities of their R&D activities.

Among the methods at hand to restrict directly the exploitation of knowledge, the patent system is one of the most commonly used by innovators. Indeed, applying for a patent or a trade mark allows an innovator to assign property rights to himself and as a result to circumvent the issue of non-excludability. In addition, the public disclosure of the patent document favors a maximum diffusion of knowledge.

Measures aimed at internalizing the externalities generated by R&D activities take the form of indirect methods to restrict the use or dissemination of knowledge. Among these measures, we can distinguish between horizontal and vertical strategies. Co-operative research activities such as joint ventures typically refer to the former type of strategy. In addition, technological co-operation involves further advantages such as increasing the benefits from cost sharing, risk pooling, exploiting economies of scale in R&D, eliminating ‘excessive duplication’ of R&D projects and pooling of complementary skills. On the other hand, the main drawback of co-operative activities is that it creates monopoly in both the R&D and output markets which in turn generates price distortions. One of the main reasons underlying the development of vertical strategies is the need to have access to specialized complementary assets in order to commercialize or produce the innovation.

In addition to these policies, firms may improve their appropriability by keeping the outcomes of their innovative activities secret. They can also increase the demand for their

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30 For a more formal review, see Geroski (1995) or Mowery (1995).
innovations by increasing their sales or marketing efforts. Finally, being the first to innovate confers certain advantages such as lead time and learning curve advantages.

2.5. OUTCOME OF TECHNOLOGICAL CHANGE

It is a commonplace to state that the process of technological change influences many aspects of the economic and social life\(^{31}\). This section discusses some of the most important economic effects of technological activities.

Patent statistics are the most widely used indicator for the measurement of the output of technological activities and therefore they constitute a convenient measure of the effectiveness of technological activities. However, many economists have questioned the reliability and validity of patents as a measure of the outcomes of technological activities. One of the main criticism addressed to patent data is that since they are a record of invention, they occur at an early stage of the process of technological change. Consequently, patents are often treated as an intermediate output of technological activities. Another drawback of patent measures is that not all new inventions are patented and patents vary greatly in their economic impact (Pakes and Griliches, 1984)\(^{32}\). One reason is that inventions have to be successfully developed into marketable product or process innovations in order to receive a positive economic value.

According to Rosenberg (1983), technical progress is constituted by certain types of knowledge that make it possible to produce a greater volume of output, or a qualitatively superior output from a given amount of resources. Another direct consequence of technological change is that it generally affects the efficiency of the production factors, and as a result, the demand for these inputs. In the neoclassical tradition, three kinds of effects of technological change are distinguished: neutral, labor-saving and capital-saving. Hence, a new technology is said to be neutral when it raises the marginal productivity of labor and capital in the same proportion and is said to be labor-saving or capital-saving when it raises the marginal

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\(^{31}\) To name just a few of them, productivity, commercial performances, e.g. exports, patent applications, employment, production costs or production factors’ reallocation, e.g. wages, interest rates, profits, market structure, inflation, competition, quality of goods and services, economic growth, welfare, e.g. the satisfaction of individual and collective needs, are variables affected by technological activities undertaken by firms.

\(^{32}\) A more complete discussion of the limitations of patents as a measure of the output of technological activities is provided in Chapter 4.
productivity of capital more or less than that of labor, the amounts of the factors being unchanged (Robinson, 1938).

Similarly, technological change has been classified according to whether it increases output (Hicks-neutrality, i.e. the marginal rate of substitution is left unchanged at a constant capital-labor ratio), labor (Harrod-neutrality, i.e. the capital-output ratio is left unchanged at a constant rate of return to capital) or capital (Solow-neutrality, i.e. the labor-output ratio is left unchanged at a constant wage rate). It should still be noted however, that in practice it is not obvious to disentangle between these three types of effects.

For more than 30 years, economists have been trying to quantify the contribution of technological progress upon economic growth. Though the numerous studies which have attempted to carry out this measurement exercise are full of pitfalls, both conceptual and methodological, they all point to the recognition of the major role played by technical progress in economic growth, leaving the increase in quantity of capital and labor input accounting for a very small share.

As it has been argued before, one economic incentive that motivate firms to undertake technological activities is the expectation of some economic benefit, net of the incurred costs, deriving from the innovation. These profits may arise for several reasons: decreased production costs in the case of cost reducing innovations, increased market share thanks to new product innovations replacing old technologies become obsolete; royalties or fixed fees; e.g. an independent inventor licensing his discovery to a firm. It should be noted that the profit incentive to undertake innovative R&D activities may not be the same under different market structures and according to whether the innovator is an incumbent or an entrant. For instance, as shown by Scherer (1980), when a cost-reducing process innovation is introduced to a perfectly competitive market, the innovator can appropriate the full cost reduction over an increased output volume, since his actions will not influence market price. At the other end, in a monopoly the profit incentive is lower since the innovator faces a declining demand curve and as a result, he has to share his rent with the consumers. In addition, the lower cost curve resulting from the cost-reducing innovation will diminish prices and increase output. However, for entrants, this conclusion is somewhat different. As Arrow (1962) demonstrated, not only

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33 See the pioneering works of Abramowitz (1956), Solow (1957) and Denison (1967).
entrants benefit from lower costs resulting from their process innovation, but also from raised profitability inherent to monopoly.

2.6. CONCLUSION

Research and development activities are the most important source by which firms acquire and generate new technological information. These activities represent a non negligible part of the GNP’s of industrialized countries. Furthermore, these activities gain in importance over time. On average, for the OECD countries, the ratio of R&D to GNP is about 1.5% in 1993 as compared to 1.3% in the early eighties. However, this ratio is somewhat higher for the US and Japan than for the EU. Besides R&D, business R&D personnel and patent applications are two other indicators widely used by economists to measure innovative activities. These indicators too, give clue that the pattern of technological activities differs strongly across geographic areas and increases over time.

Technological change is very often viewed as a threefold process: invention, innovation, and diffusion. These stages do not constitute a linear sequence, but rather a set of activities characterized by important feedback effects and selective mechanisms. R&D activities can vary according to the technological stage they refer to. Hence, it is common to distinguish between the two components of R&D. Research itself can be fundamental or applied in scope. Yet, R&D are not the only means by which firms carry out innovative activities. The acquisition and use of external knowledge can be achieved through other ‘channels’ such as reverse engineering, purchases of high technology goods or licenses, attendance at conferences, hiring of R&D personnel, or technological collaboration with other firms, research centers, or universities. Finally, the funds required to finance technological activities may come from internally generated funds, i.e. internal financing, or from debt and equity, i.e. external financing. Public authorities can support firms’ technological activities thanks to subsidies or fiscal incentives.

R&D activities constitute one of the elements that characterizes the process underlying technological change. Other factors that enhance or possibly undermine this process have to be considered as well. Figure 2.7 summarizes these main determinants as well as some of the main economic outcomes of technological change. Among the main technological determinants we
can distinguish between technology push, demand pull, geographic and institutional factors. The number of patent applications is often considered as an intermediate outcome of R&D activities. Since these activities consist in new product and process innovations, they are likely to affect the firms’ total factor productivity.

How can we measure the impact of the technological determinants on firms’ technological performances as measured by patent applications? What is the contribution of these activities on firms’ productivity performances? How can we characterize and differentiate all these effect and assess them quantitatively? Chapter 4 examines the relationship between the main determinants of technological activities and patent applications. In particular, the timing of patenting activities is investigated. The contribution of the stock of R&D capital as a source of productivity growth across firms of different industries and geographic areas is explored in Chapter 5. Finally the last chapter of the thesis addresses the question of the importance of technological spillovers on firms’ productivity increases. A special attention is given to the way this determinant can be formalized and its effect measured empirically. Before discussing the main outlines of the conceptual and methodological framework to quantify the relationship between, R&D, the technological determinants and the economic outcomes that result from these activities, the construction and the characteristics of the Large International Technology Enterprises on which the subsequent empirical analysis is based on is presented in Chapter 3.
Figure 2.7 Determinants and outcomes of technological activities

**Techno-push factors**
- technological opportunity
- technological spillovers
- diffusion
- competitive

**Geographic factors**
- resource endowments
- cultural factors

**Institutional factors**
- S&T policies
- Higher Education Inst.
- Research & Techn. Org.
- bridging institutions
- Venture Capital Org.

**Demand-pull factors**
- market power (ex-ante)
- replacement effect
- preventive effect
- market power (ex-post)
- market demand
- firm’s size
- internal resources
- diversification
- loss of managerial control
- researcher’s incentives

**TECHNOLOGICAL ACTIVITIES**

**INPUT**
- R&D
- L r&d
- C r&d

**knowledge production function**
- indivisibilities
- risk
- uncertainties

**OUTPUT**
- innovation
- process
- product

**OUTCOMES OF TECHNOLOGICAL ACTIVITIES**
- patent applications
- total factor productivity
- production costs
- production factors’ reallocation
- exports
- market structure
- profits