Introduction

The subject of this book is research and development (R&D) evaluation and performance measurement. For the largest part of the twentieth century, establishing effective forms of control for R&D undertaken at either industrial or governmental level was considered a very challenging task. In order to understand the reasons underlying this unfavourable attitude toward R&D performance management, it is necessary to clarify first the scope and purposes of R&D. An established taxonomy of the activities included in the R&D concept distinguishes between basic research, applied research and new product development (NPD). Basic research has the purpose to produce new knowledge about the principles underlying natural and social phenomena, without any direct relationships with industrial applications (for example, new products, services or industrial processes). Applied research is aimed at the generation of new knowledge required to fulfil explicit needs and to enable industrial applications. Finally, NPD includes a number of heterogeneous tasks (that is, design, prototyping, testing, engineering, installation, after-sales services) that are necessary to apply existing bodies of knowledge to the development of new products or services.

CHALLENGES IN R&D PERFORMANCE MEASUREMENT AND EVALUATION

From this definition it clearly follows that the most important outcome of basic and applied research is represented by new knowledge, new technologies, new bodies of competencies, that have intrinsically an intangible nature. An objective system for the measurement and evaluation of these intangible results is therefore very hard to establish, because no appropriate quantitative indicators can be designed and applied. On the contrary, NPD does produce tangible results, in the form of new products and services that are sold on the market, generate revenues and hence can be associated with quantitative measures of performance. However, the outcome of NPD becomes manifest a long time after design and engineering activities are carried out. The NPD process for a new drug might take for instance 10 years to be completed. As a result, evaluating design and engineering

performance measuring their tangible outcomes is practically unfeasible. Input measures for both basic and applied research and NPD, which use as proxy of R&D performance the resources available to undertake them (in terms of R&D expenses or number of R&D employees), could mitigate this problem. However, this form of control is largely inappropriate, as R&D activities are often serendipitous and their performance radically influenced by the experience and creativity of R&D professionals, which is something that is not mirrored in input indicators. Differently put, a larger availability of higher level resources does not necessarily lead to superior performance in R&D.

Last but not least, R&D is fundamentally dependent on the creative and innovative behaviour of researchers, scientists and engineers. Any form of control, be it input-, output-, or process-based, can potentially thwart this behaviour and hence undermine a critical success factor in R&D. These are the reasons behind the limited attention devoted by both academics and practitioners to R&D evaluation and performance measurement for most of the twentieth century.

A RENEWED INTEREST IN R&D PERFORMANCE MEASUREMENT AND EVALUATION

However, during the 1980s and 1990s some changes have occurred in the economic and social environment that have stimulated managers', policy makers' and researchers' attention to the issue of R&D performance measurement and have encouraged the development of new approaches able to overcome, or at least minimize, the above mentioned barriers to an effective evaluation. First, technology has been advancing more and more rapidly, as new knowledge has been developed and applied to products and services faster and faster (Bayus, 1994; Wind and Mahajan, 1997). As a consequence, life-cycles have reduced in several product categories (Nevens et al., 1990), a higher number of new products and services have been introduced over time, and the distance between subsequent innovations has decreased (Bayus, 1998). In parallel, markets have become more and more turbulent and dynamic: customer needs, competitors, business models and the set of competencies necessary to compete in a definite industry, are nowadays changing over time with an unprecedented frequency (Mohr et al., 2005). Moreover, globalization, liberalization and convergence of markets and technologies have increased competition in several industries, both at a domestic and at a global level (Gupta and Wilemon, 1996).

As a result of these changes, firms and countries have increasingly

Source: Adapted from National Science Foundation (2008). Data on European research and development include data related to Germany, France, United Kingdom and Italy.

Figure I.1 Research and development investments (US\$ billions)

looked at the capability to develop continuously both incremental and radical new products, services and technologies, and therefore at excellence in R&D activities, as critical determinants of their competitiveness. A knowledge-based society, where wealth is mainly dependent on the ownership or control of critical competencies and technologies, has emerged and replaced an industrial paradigm fundamentally associated with a machine-based model of productivity. At the same time, R&D activities have become increasingly costly. The cost of developing a new drug, for example, is nowadays well over \$800 million, more than ten times the level it reached in the mid 1990s. This is partially the result of the so-called technology fusion phenomenon (Kodama, 1995), whereby radically new products and services are increasingly the result of the merging and integration of competencies traditionally belonging to distinct disciplines, that therefore need to be mastered or anyhow acquired to achieve excellence in R&D. The growing magnitude of R&D expenses in the last two decades is corroborated by the data reported in Figure I.1, which shows the uninterrupted growth of total R&D investments in Europe, the United States and Japan, measured in absolute terms.

Within the context described above, the last two decades have witnessed an exponential growth in practitioners' attention toward R&D performance and, as a result, toward its measurement and control. In particular, scholars in management and economics have started addressing the

problem of R&D evaluation under different perspectives and employing different units of analysis:

1. *Firm* A first line of research has adopted the point of view of a firm's executives and R&D managers and has looked into the problem of measuring R&D's contribution to economic value creation and competitive advantage. Some examples of the issues addressed at this level of analysis are: the design and implementation of a performance measurement system (PMS) to be applied to the firm's R&D units and laboratories (Kerssens-van Drongelen and Cook, 1997); the development and use of appropriate techniques for the evaluation of R&D projects; (Cooper et al., 2001; Poh et al., 2001); and the introduction of performance assessment and rewarding systems for R&D professionals (Farris and Cordero, 2002).

2. *Financial markets* A second stream of research has instead adopted the standpoint of financial markets and has studied the relationships between traded firms' R&D investments and their market value. (Chan et al., 1990; Munari et al., 2005). An important topic that has received special attention within this body of research encompasses the anatomy and effects of the flow of information about R&D investments and the information asymmetries between companies and financial investors, which are mediated by the information disclosing rules that accounting standards establish (Hand, 2001, 2003b).

3. *Innovation system* A last line of research has adopted a broader perspective, studying the problem of measuring R&D at the level of national or regional innovation systems, whereby a national innovation system can be defined as 'the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies' (Freeman, 1987, p. 1). Within this vast stream of research, scholars have investigated some important issues such as the use of bibliometric, technometric and patent-based indicators to evaluate R&D carried out within a national innovation system and the assessment of R&D policies' effectiveness (Feller, 2002; Foray, 2004).

GAPS IN THE EXISTING LITERATURE

Despite the attention devoted to the measurement of R&D performance in the last two decades, a comprehensive picture of the techniques and approaches developed and applied by researchers and practitioners at the different levels of analysis (firm, financial markets and innovation system)

has not been provided yet, and a number of issues still need to be fully unearthed. As a result, extant literature is highly fragmentary, and further research is needed to study how the different methods and perspectives could be integrated into a unified framework of analysis. What is more, a number of changes have recently occurred that have a deep impact on the approaches that managers and policy makers use to assess R&D performance. In particular, the management and organization of R&D activities have undergone a significant evolution as a result of (see also Chiesa and Frattini, 2008):

1. Increased reliance upon external sources of technology Firms often lack the technical and financial resources needed to develop the whole set of competencies required for effective R&D and innovation. As a result, they increasingly concentrate and specialize their internal R&D efforts on those core activities where they are more likely to excel. At the same time, they learn to leverage external sources of technology (for example, universities, competitors, firms from other industries, individuals) to acquire the missing competencies and to continuously feed their innovation pipeline (Chatterji, 1996; Howells, 1999; Roberts, 2001).

2. Leverage multiple channels for technology exploitation In the past, companies have generally incorporated the results of their R&D activities into new or improved products and services to be internally developed and launched in the final market. However, the high costs required for technology development and the soaring rate at which new knowledge is produced, make long term competitive advantage increasingly dependent on a firm's capability to continuously and fully leverage its technology basis. As a result, firms are contemporarily exploiting multiple paths for converting their technologies into revenues, among which external exploitation approaches (for example, licensing out, new venture spin-off, joint ventures, contract research) are increasingly diffused (Haour, 2004; Mohr et al., 2005).

3. Entrepreneurial nature of R&D R&D has been traditionally conceived as a part of the firm's overhead costs (Ortt and Smits, 2006) and administered as a technology-focused function where the firm's body of knowledge was generated, protected and transformed into new or improved products and services. Nowadays, internal R&D is still the repository of the firm's core technological competencies but, at the same time, it has become the engine of the innovation process and undertakes a number of critical business-related, brokering activities, for example the scouting of the external environment for the identification of valuable sources of knowledge, the

integration of internally generated with externally acquired technologies, and the pursuit of external exploitation opportunities for internal technologies. A value-based approach, where R&D is responsible for the business results it delivers, has therefore developed and diffused (Ortt and Smits, 2006).

4. Birth and growth of markets for technology The search for multiple channels for exploiting a firm's competencies and technologies, the specialization in knowledge development and the associated division of labour in innovative activities, have contributed to the development of the so-called markets for technology (Arora et al., 2001). The capability to interact with the players on these markets, where knowledge disembodied from physical artefacts is exchanged, has become a critical capability for R&D organizations (Jones et al., 2000; Muller and Zenker, 2001).

5. Management of R&D on an international scale Finally, the management of R&D has assumed an international dimension. A number of pieces of research on the internationalization of innovation activities clearly show that foreign R&D is becoming a significant component of many countries' R&D base (Jones and Teegen, 2002; United Nations, 2005).

These changes in the management of R&D have been captured and systematized in the well-known paradigm of industrial innovation called 'open innovation' (Chesbrough, 2003a). Under this new approach, the role of R&D and the approaches used to administer it have become radically different from those employed in traditional innovations models. This has relevant implications also for the evaluation and performance measurement of R&D, at the firm-, financial markets-, and innovation system-level from which the issue can be addressed and studied.

CONTENT AND STRUCTURE OF THE BOOK

That said, this book has two main purposes:

1. Provide a systematic and updated overview of the existing literature on R&D evaluation and performance measurement organized around the three levels of analysis (firm, financial markets, innovation system) presented above in this introduction;
2. Describe the results of the research project carried out by the authors and the other contributors of the book in the last three years to address

some important gaps in the existing research on R&D evaluation and performance measurement and, more importantly, to investigate the impact that the recent changes in the management and organization of R&D activities is having on the methods and approaches used to assess its performance.

In doing so, the book develops and illustrates a comprehensive, integrated and multi-level framework that represents an original synthesis of the most recent research on the techniques and perspectives that can be used to evaluate R&D and to measure its performance at the firm-, financial markets-, and innovation system-level. The book is targeted mainly at an academic audience, made up of scholars and Ph.D. students in management and economics, whose research interests are related to R&D, technological innovation, performance measurement and evaluation. Therefore, particular attention has been devoted to reviewing and commenting on the most important literature contributions for each level of analysis, and to describing the methodological details of the empirical studies carried out by the authors and the other contributors to fill specific gaps in the existing literature. These details have been presented in the belief that they will improve the value of the book for its intended audience, who will hopefully find its framework a valuable starting point for future research into the complex and challenging topic of R&D performance measurement and evaluation.

The book is organized into three parts that correspond to the three perspectives mentioned above in this introduction, under which the problem of R&D performance measurement and evaluation can be analysed and studied. Part I (Firm) addresses R&D performance measurement from the point of view of a firm's executives and R&D managers who are interested in assessing the contribution of R&D to economic value creation, in monitoring R&D activities' efficiency and effectiveness and in evaluating R&D professionals' performance to better motivate, reward and retain them. Part I has three chapters, each adopting a specific unit of analysis:

1. Chapter 1 (R&D function) focuses on the R&D function of an industrial firm and investigates the techniques that can be used to measure its performance. The first part of the chapter provides a detailed literature overview of the methods that can be used with this purpose. The second part focuses on a topic that has been relatively overlooked by extant research, namely the design of an integrated performance measurement system (or PMS) for the firm's R&D function. Although a number of contributions have looked into specific aspects of this problem (for example, which indicators or metrics are best suited to

the characteristics of R&D activities, which is the optimal measurement frequency in R&D settings), very few of them have addressed it in a comprehensive manner. Relying on the results of a three-year empirical study, a reference framework for the design of a PMS for the R&D function is developed and illustrated. The chapter has two appendixes. The first one describes the application of the framework to a highly innovative biotech firm. The second one reports a detailed description of the empirical analysis that has been undertaken to develop the above mentioned reference framework.

2. Chapter 2 (R&D projects) adopts the single R&D project and the firm's portfolio of R&D projects as units of analysis. The chapter first focuses on the techniques that can be employed for the evaluation of single R&D projects. A taxonomy of the main classes of techniques that can be used with this purpose is illustrated and developed through a systematic review of the relevant academic and practitioners' literature, and through a focus group where a number of R&D managers, from some of the largest and most innovative Italian firms, were invited to comment on the subject. In particular, the chapter discusses the contexts (defined, for example, in terms of type of R&D project being undertaken) in which each evaluation technique might be more appropriate. This represents an important contribution to the existing research on the topic, which has dedicated limited attention so far to looking into the fields of application for which different classes of R&D project evaluation approaches are most suitable. The second part of the chapter focuses on the firm's portfolio of R&D projects to investigate the techniques and the approaches that can be employed to evaluate its adequacy and the extent to which it is consistent with the firm's R&D and innovation strategy. An appendix to the chapter reports and discusses the case of a multinational firm that uses a very formalized process for the evaluation of its R&D projects, representing an original approach through which the techniques presented above can be combined to provide a more accurate evaluation. The case study allows reflection and comment on the organizational and managerial problems that may arise in the implementation and practical use of an evaluation technique.
3. Chapter 3 (R&D people) focuses on the human resources management (HRM) practices adopted by industrial firms in their R&D laboratories. The chapter first reviews the existing literature about HRM practices used in R&D settings. Particular emphasis is given here to understanding how performance measurement and evaluation systems might contribute to improving the different areas around which HRM for R&D people can be organized and studied.

The chapter then develops a framework that can be used to analyse and evaluate the degree to which the HRM system for R&D professionals adopted by an industrial firm is aligned with its competitive strategy and environment. This model is then used to support an extensive empirical analysis, which has involved a number of leading Italian firms and investigates the micro-organizational effect of Open Innovation on the management and evaluation of R&D professionals. An appendix to the chapter provides some methodological details about the empirical analysis that will hopefully inform future research into the matter.

Part II (Financial Markets) adopts instead the whole firm as the unit of analysis and studies R&D evaluation from the point of view of financial investors, who are interested in estimating the impact of firm-level R&D investments on the value of the traded company. Part II has two chapters:

1. Chapter 4 (R&D and financial investors) focuses on the relationship between R&D investments and the market value of traded firms, explaining why and how R&D investments should be reflected into financial investors' valuations and stock market prices. The chapter first reviews the theoretical and empirical foundations of the relationship between R&D investments and market value. Afterwards, it illustrates and discusses the two main classes of empirical models that can be used to analyse this relationship:
 - (a) models that relate the flow or the stock of R&D investments to the market value of the firm (often measured relative to tangible assets, that is, as Tobin's Q) at a given moment in time;
 - (b) models that relate the arrival of new information on R&D investments (R&D announcements) with changes in the stock price (stock returns).

Finally, the empirical results obtained from the application of the models are described answering to three main questions: whether R&D investments create value, how investors deal with uncertainty, and how different financial markets and ownership structures affect the market valuation of firms' R&D investments.

2. Chapter 5 (R&D information) deals with the possible R&D information problems arising between traded firms' managers and outside investors, analysing in detail how information flows from companies to investors and the implications for their market value. Three important aspects are addressed in this chapter. First, it explains why and how R&D investments generate information asymmetries between

insiders (managers) and outsiders (investors). Second, it analyses the value relevance of R&D information for investors and stock prices. Third, it focuses on the role of financial analysts, as they normally complement public R&D information with private information supporting investors' decisions. These questions are also examined in light of the changing international accounting standards and in particular the adoption of the International Accounting Standards (IAS/IFRS) by European traded firms in 2005. In this respect, the chapter reports some descriptive evidence on the effect that the application of IAS/IFRS standards has on R&D reporting for a sample of companies publicly traded in Italy. A first appendix to the chapter illustrates the models that can be used in contemporaneous and intertemporal studies to examine the relationship between R&D information disclosure and stock price. A second appendix provides methodological details about the empirical investigation.

Finally, Part III (Innovation System) broadens the scope of the analysis to focus on the evaluation of R&D activities undertaken by networks of institutions in the public or private sector and the initiatives promoted by governmental bodies to stimulate R&D activities and streamline the production and diffusion of new technologies in an innovation system. It focuses in particular on two topics:

1. Chapter 6 (Technology platform) deals with the analysis and evaluation of technology platforms. Technology platforms are initiatives recently promoted by the European Commission that bring together a number of important stakeholders with the aim of defining long-term R&D projects and technological development objectives in areas that are critical for Europe's future growth. They represent therefore an important means for vertical and horizontal coordination of R&D activities at the European level, although they have been dedicated scant attention so far in terms of assessment and evaluation of their performance. The chapter first reviews the theoretical rationale underlying the need for a systemic, inter-organizational view of knowledge production and dissemination to properly interpret differentials in firms' innovation capabilities. This explains the system-level implications of the Open Innovation paradigm. Next, the chapter illustrates the concept of technology platforms, explaining how they are created and administered at the European level, making explicit reference to a real-word case, the ACARE (Advisory Council for Aeronautics Research in Europe) European Technology Platform. Finally, the chapter develops and illustrates a framework for the assessment of a

technology platform that uses a process-based evaluation approach and distinguishes between a macro- and a micro-level at which the platform's proficiency can be diagnosed.

2. Chapter 7 (R&D policy) adopts as unit of analysis R&D policies, to provide a systematic picture of the methods that can be employed to evaluate their performance. The chapter reports first a detailed analysis of the theoretical reasons underlying the need for R&D policy intervention in modern economies. Next, it systematically reviews the literature contributions that have addressed so far the problem of why and how the effectiveness and efficiency of R&D policies should be measured and assessed. This analysis is used to develop an original taxonomy of the approaches that can be employed in practice to undertake this kind of evaluation. The taxonomy is based on two dimensions: evaluation methodologies and evaluation typologies. The first dimension distinguishes between qualitative (benchmarking and case study) and quantitative (evaluation of measurable effects and evaluation of detectable effects) methods. The latter classifies policies on the basis of their target (that is, firms, knowledge generating institutions or networking) and instrument (financial or legislative). In the second part of the chapter, this original taxonomy is used to support a thorough analysis of the empirical studies available in the literature that have applied the above mentioned methodologies to tackle real-world evaluation problems.

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