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Innovation Policy for Knowledge Production and R&D: the Investment Portfolio Approach

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Abstract

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Keywords: Innovation system; innovation policy; knowledge production; R&D; universities; innovation policy instruments

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1. Introduction

Who produces scientific and technical knowledge these days? What type of knowledge is being produced and for what purposes? Why are firms and governments funding research and development? This chapter studies these questions by looking at the role of knowledge production (and especially R&D activities) in the innovation process from an innovation system perspective. There are in fact several possible answers due to the fact that societies and economies organize the production of knowledge and R&D activities in different ways. Naturally, not all of these are equally successful when it comes to attaining the various general goals of economic growth, environmental sustainability, public health, consumer protection, etc. This chapter begins by acknowledging this diversity in terms of socio-economic organization and in terms of these diverse goals of innovation policy. The chapter aims to provide a consistent conceptual and theoretical framework based on the innovation systems approach which will serve to capture and analyse these systemic differences as well as the most relevant recent trends in innovation policy.

Innovations can be defined as new creations of economic or societal significance. Following most of the literature in these matters, innovation is related to the emergence, diffusion and combination of knowledge and their transformation into new products or processes. Seen from this perspective, innovation and innovative activities are intrinsically related to knowledge, which can be either entirely new knowledge, or it can also be old/existing knowledge which is being combined and used in new ways. For this reason, the production of knowledge and its development is a fundamental activity in any innovation system, albeit not the only one (Edquist 2011).

This chapter proceeds as follows. The next section discusses the role of knowledge production in the innovation process from a perspective of innovation systems. It pays special attention to "research and development" (R&D) as a specific and crucial activity related to knowledge production. In so doing this section examines who produces R&D and what types of R&D. The chapter then examines one of the most crucial issues for innovation policy-makers from the perspective of investment portfolio[1] in an innovation system as well as its respective returns. Knowledge production in innovation systems has been experiencing important transformations over the past two decades. In this chapter we focus on two specific themes, namely, the transformations in direct and indirect public funding to knowledge production and the rapid transformations in the governance of research universities (here mainly the autonomy of universities – or lack thereof, and the measurement of research universities outputs).

The following section examines the critical and most important issues at stake from the point of view of innovation policy, looking particularly at the unresolved tensions and systemic unbalances related to knowledge production in the system. Finally, the concluding section elaborates a set of overall criteria

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[1]See definition of "investment portfolio" in Section 3 below.

for the selection and design of relevant policy instruments and addresses those tensions and unbalances.

2. Knowledge and R&D in the Innovation System

The innovation system approach sees the production of knowledge (and R&D in particular) as a crucial element in any innovation system, economy and society. It is crucial but not as the "linear view" suggests. In contrast to the automatic, direct, mono-causal link between the "amount" of knowledge and R&D activities and the innovativeness of that economy suggested by the linear model, the innovation system perspective argues that this relationship is much more complex and not necessarily direct.

From the current perspective on innovation systems, we can distinguish between a broad definition of knowledge and a more specific definition of R&D. The box below conceptually clarifies "knowledge production", "research" and "development".

Box 1: Knowledge production, research and development - Concepts

Knowledge production refers to the creation of new knowledge. This is the widest concept and does not necessarily refer to scientific and technical knowledge but all sorts of new knowledge.

Research refers to the production of knowledge by using scientific and technical methods.

Development refers to the production and the adaptation of new knowledge in its use context, typically related to processes of prototyping, demonstration, testing, certification, modelling, scale modelling, proof of concept and clinical trials.

As the box indicates, "knowledge" is the widest notion. Hence, knowledge is not the same as R&D, which refers to the type of knowledge produced by scientific and technical methods. An example of this is a patient organization that produces relevant knowledge by collecting information about certain observed secondary effects of a specific drug. This knowledge is relevant for the patients themselves, as well as for authorities and the producing firm. The patient organization may decide to send that knowledge to the firm and to the relevant authorities for further analysis but as such, the knowledge of the patient organization may not necessarily be the direct result of R&D activities but simply the collection and desktop interpretation of specific observations.

Admittedly, the borderline between knowledge production and R&D is difficult to trace with exactitude. This is so because from an innovation system perspective, the production of knowledge and R&D is largely contingent to the wider contextual and social dynamics that are unique to each society. Knowledge and R&D are highly embedded in the social, cultural and political contexts that are unique to

each society and time. This is the reason why the specific features and idiosyncrasies of different forms of organizing knowledge production and research and development activities are not replicable elsewhere or at other points in time. This is important when designing innovation policy. Policy initiatives aiming at fostering the production of knowledge, as well as research and development, must take these societal, economic and organizational contexts into account.

But what is knowledge and what type of knowledge exists? This a very relevant question because there are a multitude of different views on knowledge types. One of the most influential understandings of knowledge and knowledge types was made by ancient Greek philosophers when Plato defined knowledge as "justified true belief". The Greeks distinguished between "episteme" a form of knowledge which is based on disinterested understanding and contemplation (not involving the act of doing manual work) and "techné", which is the context-based, applied knowledge that derives from manual work and craftsmanship. This ancient distinction is behind the conventional division between basic research and applied research. Although it continues to enjoy wide acceptance in policy-making circles, this division has been contested on the grounds of the complex nature of knowledge (some types of knowledge are both basic and applied) and on the grounds of the particular dynamics of knowledge production (some scientists, such as Louis Pasteur, do basic and applied science simultaneously) (Stokes 1997).

An alternative and perhaps more useful distinction looks at the ultimate purpose of knowledge production. Here the distinction is between curiosity-driven and utility-driven knowledge (Strandburg 2005, van den Hove 2007). Partly overlapping, there is also a distinction between knowledge that is a fundamental discovery and knowledge that is a technical invention. The latter has been quite relevant in the political and legal discussions of patent law when trying to determine the limits on what type of knowledge can be patented.

This later remark raises another distinction, namely the one between tacit and codified knowledge. The debates surrounding their respective nature and their relative importance in the knowledge-based economy have been quite intense (Cowan, David et al. 2000, Johnson, Lorenz et al. 2002). The backdrop of these discussions was the so-called "patent era", or the increasing trend in knowledge appropriation and commercialization through the issuing of patenting rights (a form of codified knowledge) (Foray 2001).

These discussions evolved towards a different approach, namely the different types of "knowledge-bases" in innovation systems. Here, a distinction has been made between STI (Science, Technology, Invention) and DUI (Doing, Using, Interacting) types of knowledge (Jensen, Johnson et al. 2007) or in another version, analytical knowledge base and synthetic knowledge base in local or regional economies (Asheim and Coenen 2006). All innovation systems have both types of knowledge bases but one of the knowledge bases tends to be predominant over the other. The relative presence of these knowledge bases shapes the particular dynamics of innovation in a system.

Naturally, the borderlines between techné/episteme, basic/applied science, curiosity-driven/utility-driven knowledge; fundamental discovery/technical invention; tacit/codified knowledge; synthetic/analytical knowledge bases are very fluid and can always be challenged. However, they are

still valid for analytical reasons: they can help us grasp the complex dynamics, processes and purposes of knowledge production and their use and what is most important, they can help us understand on what grounds innovation policy-makers have made decisions. This is to say, that we are not interested in an ontological discussion about the nature and types of knowledge per se, nor in what types of knowledge are more important in the innovation system and for innovation policy. Rather, we are interested in understanding the way in which these distinctions have been influential in innovation policy-making and in crucial decisions regarding the allocation of private and public investments.

This chapter focuses on a specific sub-set of knowledge production, namely the knowledge that is produced through research and development activities (R&D). As seen in Box 1, Research and Development is a very composite and heterogeneous activity. A useful way of studying R&D in an innovation system is to consider the actors that produce it. This can provide a useful analytical tool and a snapshot regarding the "who" and "what" of R&D activities at a specific given point in time and its changes through time. Naturally, these are schematic and representative tools that could be combined with indicators and other analytical instruments.

Following from the discussions above regarding the nature of knowledge and the context in which it is produced and being particularly inspired by the Pasteur's Quadrant (Stokes 1997) and its subsequent elaborations (Guinet 2009), we can consider two crucial dimensions for the study of R&D and knowledge production in an innovation system.

The first dimension follows from the discussions above, and in particular, from the distinction between fundamental discovery and technical invention. This distinction has naturally been questioned as it is difficult to draw the line between one and the other. Naturally, the boundaries between them are not at all as clear cut as may seem at first sight. However, it serves here as a heuristic to grasp analytically different logics behind R&D.

The second important dimension looks at the exploration or exploitation of knowledge (March 1991). This is the distinction between R&D that is directed more towards the exploration of new frontiers of knowledge (curiosity-driven; basic science) and the R&D activities that are geared towards the exploitation of that knowledge with a specific purpose (profit or non-profit). In most South East Asian countries, emphasis on the exploitation and development side of R&D activities was a strategy for a rapid catch-up process in the 1970s and 1980s, combining the imitation and exploitation of existing knowledge with its further development at product level (Kim 1997).

The mapping in Figure 1 visualizes the spaces these R&D producers occupy along these two dimensions. The specific cases of organizations located in these two dimensions illustrate a generic example. In analytical terms, mapping the different R&D organizations of an innovation system along these two dimensions allows strengths and weaknesses to be identified in terms of possible duplications, as well as empty spaces of R&D activities in a system. It can also help to compare R&D strengths and weaknesses across countries or regions. This may help to design innovation policy.

Figure 1: Mapping R&D organizations in innovation systems - a generic illustration.
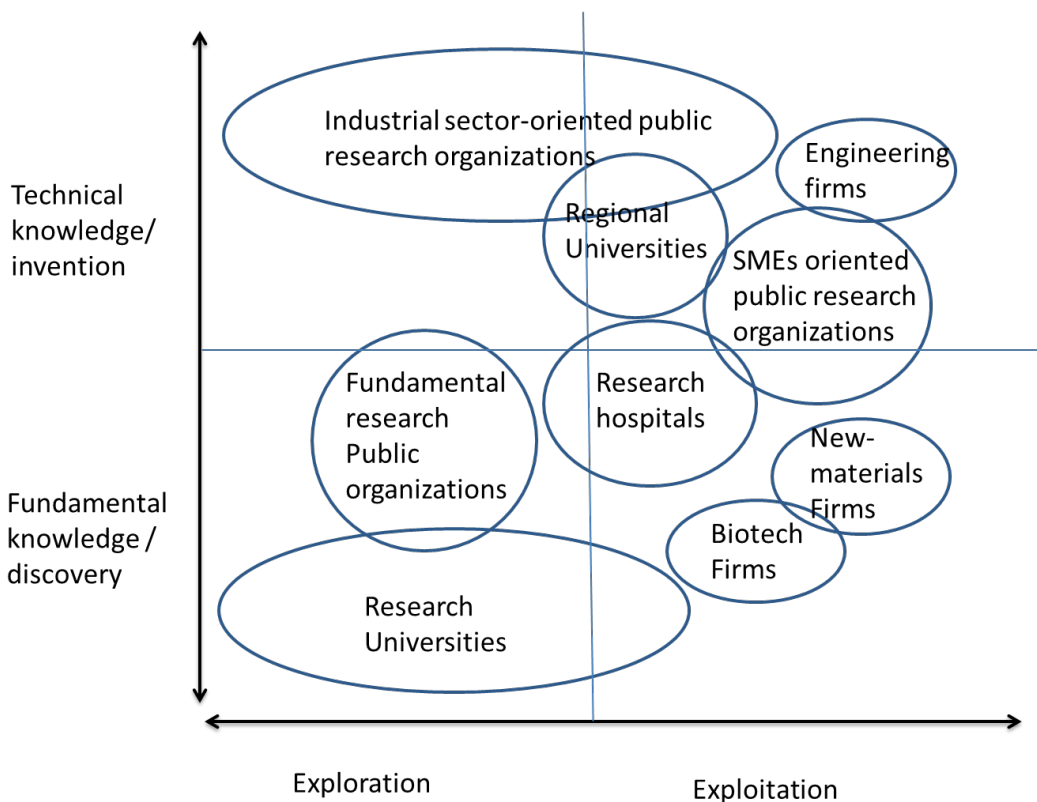
3. R&D Investment Portfolio and its Returns

When looking at the R&D that is being generated in an innovation system, two considerations are paramount. First, given its centrality for social as well as for economic development, R&D is to be considered an investment (rather than expenditure)[2]. This perspective induces us to look at R&D as an investment portfolio. Following the business literature, by "investment portfolio" we refer to the set of different investments that public funding agencies and private actors make to produce knowledge and R&D activities in an innovation system. These investments can be different in terms of the time perspective of the investment (long or short term) and in terms of the different levels of expected risks

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[2]R&D has traditionally been accounted as "expenditure" rather than "investment" in public budgets. Yet, this is currently changing. In Spring 2013, the US started to consider R&D in its public budget formally as an investment.

and potential results. From an innovation policy point of view, as we will discuss later in this chapter, it has to do with the overall set of public policy initiatives towards knowledge production and R&D, and their features in terms of time perspective as well as risk and results.

The idea of an investment portfolio approach in the policy initiatives towards knowledge production and R&D has to do with the crucial question of whether the government places the investment well (a balance between risk and yields of returns and a balance between short and long-term, and a certain variation across different areas of knowledge) (Jackson 2006). The emergence and use of the portfolio approach allows the construction of complex project portfolios which spread risk and can thus allow the pursuit of a few highly risky projects among several other projects with a much lower risk. Public procurement and public-supported venture capital are two high-risk areas of action in a public investment portfolio. These two are more high risk oriented than conventional areas of public R&D investment, such as, for example, "development" activities (see below). Venture capital seems to be particularly high-risk since it typically entails a combination of innovative projects with entrepreneurship. For this reason, policy-makers may be inclined to support this type of activity as a form of promoting the creation of new firms with innovative capacity in the system, even if the rates of return may be low.

Second, it is paramount to examine the rate of return of that investment, both the private rates of return as much as the social rates of return. Both considerations are important from the point of view of innovation policy. Any decision regarding public support for R&D activities must have a clear notion of the nature of the (country/region's) public investment portfolio as well as its rates of return. Cost-benefit analysis is a possible analytical tool that public policy-makers may consider using to define the possible outcomes of public investments and to define the composition of the public investment portfolio.

There are roughly three funding sources of R&D investment. These are private-for-profit R&D investment (typically by firms), private-non-for-profit R&D investment conducted/funded by philanthropic or charitable organizations and public R&D investment conducted/funded by public authorities. Thus, one place to start when examining the levels of R&D investment in an innovation system is to look at the relative share of private, philanthropic and public investment. This share varies considerably across countries. A general tendency is that in countries with high levels of innovativeness in their economies, the share of private for-profit R&D investment tends to be proportionally higher than the other two.

These three types of funding sources of R&D investment indicate the "who" and partly the "how" of R&D activities in an innovation system. However, we may need to take a much closer look at how the overall investment portfolio is distributed across different knowledge areas in the innovation system. In other words, in what type of R&D a particular innovation system tends to be specialized in. Some of these investments are clearly targeted at some knowledge and industrial areas whereas others are more generic in nature (i.e. basic research public funding).

From the point of view of innovation policy, policy-makers must also define whether the existing general levels of investment and the investment portfolio are adequate vis-à-vis the collective expectations and societal goals defined (hopefully) democratically by the government and parliament. Decisions on the distribution of funds and strategic areas are naturally political decisions which are (also hopefully) made on the basis of solid knowledge about the existing portfolios as well as on the basis of the sources of strategic intelligence for innovation policy making.

Innovation policy-makers must examine and determine whether the different sources (public/private/philanthropic) of R&D investment are complementary to each other or not. Complementarity is important because one crucial issue that public R&D investment would like to avoid is a displacement effect on private sources of investment, or the effect by which public funds displace or substitute (crowding out) private investment in R&D (Jaffe 1998). Likewise, policy-makers must consider the question of whether public investment should be primarily placed in existing knowledge/industrial sectors where the economy is specialized, or on the contrary, in those sectors where there is virtually no specialization or presence but a wish or need to achieve this.

The second consideration for innovation policy makers from an innovation system perspective is the rate of private and social returns of R&D investments. The reason for this is quite obvious, namely R&D investment is expensive and it is expected to yield positive returns. Economists have dealt with the question of measuring rates of return for several decades and in different ways, either by looking at specific cases (technologies or public programs) or by conducting econometric analysis with a more macro-level perspective. The increasing availability of panel data and improved methodologies has gradually made these analyses more sophisticated and comparable; however, large uncertainties remain given that "the return to R&D is not an invariant parameter but the outcome of a complex interaction between firm strategy, competitor strategy, and stochastic macro-economic environment, much of which is unpredictable at the time a firm [or a public policy] chooses its R&D program" (Hall, Mairesse et al. 2010) p. 4.

The private rate of return to R&D refers to the return that the individual firm gets from its own investment in R&D activities. Several case studies of technologies as well as wider macro-economic analysis indicate that there are very different rates of private return across cases and across technologies (Hall, Mairesse et al. 2010) for a review). Perhaps the most relevant finding among the widespread studies of private rates of return is that there seems to be a very skewed distribution of private returns (Scherer and Harhoff 2000). By comparing different data sets, the authors find that "the lion´s share of the privately appropriated value through investments in innovation comes from roughly 10% of the technically successful prospects" (p.561). In other words, very few investments in R&D yield positive returns and they typically yield very large returns. Furthermore, nothing suggests that the skewed distribution of private rates of return may be any different from the social rates of return. In other words, few public R&D investments yield large positive social returns (Scherer and Harhoff 2000). "All this suggests the need for both nations and firms to pursue a portfolio approach to backing new technology, recognizing that only a few of the projects supported will pay off on a large scale and hoping that the generous returns from the relatively few successes will also cover the cost of the many less successful projects" (p. 562).

The rates of return may not only benefit the individual firm, they may also benefit the economy and society in a much wider sense. The social rate of return is a notion that includes the private rate of return plus the knowledge and market spillovers of these R&D activities. Hence, the social rate of return to R&D is larger than those of private returns and is closely intertwined with spillovers. The box below distinguishes between these concepts.

Box 2: Rates of returns of R&D and spillovers

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Private rate of return of R&D: the firms' rate of return from their own R&D investment.

Social rate of return: the rate of return which includes not only the private rate of return but also the knowledge and market spillovers of R&D activities (see below).

Spillover (general): an unintended transfer of market benefits to other market agents with no payment involved.

Knowledge spillover: knowledge created by one agent which is used by another agent without compensation, or with compensation that is less than the value of the knowledge.

Market spillover: when the market for a new product or process creates benefits to the consumers and to other producers through better products and lower costs.

Technology transfer: "trade in technology which occurs when an agent sells a piece of technology with a price attached to the transaction". Hall, Mairesse&Mohnen 2010 p. 25.

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As we saw above, policy makers must place R&D investment in a way that does not displace private R&D investments. In order to do so, a rule of thumb says that policy-makers must fund projects which yield high social rates of return but have low commercial prospects (Jaffe 1998). Determining ex-ante which project will have these two features is however a very difficult task, given the unpredictability of R&D investment results.

In his seminar paper from 1986, David Teece put the returns of R&D investment into a broad context (Teece 1986). He started with the remark that often innovating firms (those inventing and commercializing first) are not those who profit most from the innovation. Teece suggests that there are three factors that determine an individual firm ability to obtain profits from its own innovation. These are the appropriability regime (the way in which the patent system works for product innovations and the relative irrelevance of patenting process innovations), the complementary assets of the firm (marketing, post-sale services, etc. are crucial for an innovation to be successful) and the dominant design paradigm (what competition the new product faces in the market, whether it is a paradigmatic design or a post-paradigmatic design). Teece's paper puts firms' R&D investments in relation to innovation activities (of the firm itself and of the innovation system). This contextual approach is

paramount to understanding the factors behind higher or lower private rates of return which tend to vary across firms and systems.

A similar contextual approach has been recently emerging when studying the rates of social returns. Coming from the world of research evaluation, these new studies no longer look at the aggregated social returns of privately funded R&D activities. Instead, they look at the social returns of research and science policy programs. This is an important issue, far more when the goals of public R&D programs are not just advancing scientific and economic goals but typically other social goals such as improved public health services, carbon-free & renewable energy sources or consumer protection. Bozeman & Sarewitz study the "public value" of R&D policy in these latter terms. They conceptualize "public value" as the overall impact of R&D activities on the public goals stated in the policy documents which are typically other and more than just scientific or economic goals (Bozeman and Sarewitz 2011). This approach is a promising new way to study the impacts of public R&D policies on the self-defined "grand social challenges".

4. Research: Recent Trends in Public Funding

Continuing with our analysis of R&D investments above, we will now address how the public funding of research activities has been changing in most countries over the past few decades. Before doing that, we need to distinguish between direct and indirect public funding of research activities. Direct public funding refers to government budgetary appropriations for research activities. At first sight these are relatively easy to identify. However, sometimes research funding is distributed across different levels of government (national, sub-national, local) and across different types of public agencies in such a way that finding the exact total figure of governmental investment may not be simple. Indirect public support, for its part, refers to the tax incentives (or other type of monetary) incentives in the form of depreciations and exemptions to firms (and other taxable organizations) on the research activities they have conducted (Köhler, Laredo et al. 2012). This is an indirect support in the sense that it exempts research activities from some specific taxation obligations, with clear monetary effect for the firms in question. Direct and indirect public funding of research is a vast topic and abundant empirical literature has been dedicated to it. For this reason, this chapter focuses on the first one because it is an area of major reform and changes over the past few decades.

When examining the direct public funding of research under the prism of investment portfolio, two broad trends seem to be worth looking at. The first one has to do with the increase of competitive public funds for research vis-à-vis the traditionally non-competitive public funding. The second trend has to do with the fundamental changes in mission-oriented and diffusion-oriented public funding of research. We will examine these two trends below.

Governments have been supporting research activities since the inception of the modern state. Traditionally, this support has been in the form of direct public endowments to public (or private) universities, as well as the creation and financial support to different types of public research

organizations. In their 2007 paper, Lepori and others empirically studied the distribution of public research funding between project and non-project schemes in several European countries (Lepori, van den Besselaar et al. 2007, Lepori, Masso et al. 2009). Project funding refers to the public funding that is granted on a time-limited basis and typically the outcome of a project application process. Sometimes this project funding is competitive, but sometimes it is not.

Findings by Lepori et al show that over the past few decades the share of project-based funding has increased significantly in all countries. There are though important differences across countries in terms of the size of that share and in terms of the distribution among different types of beneficiaries (firms, universities or public research organizations). The time-limited and performance-related allocation of public research funding has had a particularly important impact for universities (Hicks 2012). If this performance measurement is conducted only on the basis of scientific rather than socio-economic performance, these allocation mechanisms may run counter to most governments' intention to enhance the diffusion and technology transfer of publicly funded research.

The second large trend over the past decades has been the changes in the orientation of public funding. In his work, Henry Ergas distinguished between two types of public research and technology policy styles (Ergas 1987). Mission-oriented research policies are those where "big science is deployed to meet big problems" p. 193. This type is when public funding of research is dominated by programmes serving specific government missions and targeted research in some areas (defence, agriculture, health, energy…). In contrast to this, countries with a diffusion-oriented policy style "seek to provide a broad capacity for adjusting to technological change throughout the industrial structure" p. 194. In these latter countries public funding of research is dominated by instruments and schemes of horizontal nature.

As indicated above, many countries have engaged in significant reforms of their public support policies for research. A rapid examination of some cases such as France, Germany or Denmark, tend to indicate that there may be a process where diffusion-oriented countries like Denmark and Germany have introduced important elements of mission-oriented policy. For example, the creation since 2001 of three different strategic research councils (and its recent merger into one) indicates Danish willingness to address more applied-based and targeted public funding. Denmark remains a country with a mainly diffusion-oriented approach but the introduction of these important instruments has introduced a relevant diversity in the Danish public funding compared with earlier. Something similar has happened in Germany, with the first High-tech strategy created in 2006. In contrast, France has experienced the introduction of a significant number of instruments and organizational reorganization geared towards more diffusion-oriented policy, including the creation of National Research Council funding research projects on a competitive basis, or the creation of the Poles de Competitivité and Carnot Institutes. This is quite remarkable for a country which tended to be one of the clearest examples of mission-oriented policies in Europe.

The extent to which these changes are the expression of convergence across some countries (or not) is still a question that remains empirically unanswered. One might expect the extensive exchange of ideas and cross-country comparative analysis at international level, as in the EU, the OECD or the World Bank, to have generated some learning among policy-makers (Borrás 2014).

5. Development: The Crucial Little Brother

So far we have mainly discussed R&D activities focusing on "research". However, R&D is quite heterogeneous. For this reason, when examining R&D from an investment portfolio approach, we need to consider other types of activities. Particularly important in this regard is "Development", which is the "D" of the R&D acronym. It encompasses a series of different yet crucial and interlinked activities in the innovation process such as prototyping, demonstration, testing, certification, modelling, scale modelling, proof of concept and clinical trials. Broadly speaking "development" or "product development" refers to the modification of an existing product or process adapting it to new needs, or the formulation of an entirely new product or process that addresses specific needs.

By definition "development" is application-related, meaning that it encompasses a set of activities whose direct purpose is to design a suitable product or process (suitable in terms of complying with user needs and, depending on the sector, complying with the legal requirements of safety too). Development is also highly sector context-specific, meaning that the precise steps and activities of the development depend to a large extent on the specific features of the industrial/knowledge sector in question. For example, the development of products in the aeronautic sector involves typically different forms of prototyping and scale modelling whereas the development of products in the pharmaceutical sector involves several steps in clinical trials.

In contrast to the "R" of R&D, the different set of activities defined here as "development" have received surprisingly little attention from scholars of innovation processes. Admittedly, the debate on different types of knowledge as well as on investment portfolio and rates of return (see sections above) has involved issues related to "development" in a very indirect way, without taking into consideration the differences between these (i.e. clinical trials are very different from prototyping). However, there are few relevant studies which analyse the social organization of development activities and their respective design-related challenges (Carlsen, Johansson et al. 2013), (Hsu and Fang 2009, Watanabe, Shin et al. 2011). These studies rarely include generalizable findings that can be used in broader analyses of innovation processes in an innovation system.

The box below provides our definitions of some of the most important generic types of development activities.

Box 3: Some generic types of development activities

Prototyping: an early sample of a product in order to test its design, functionality and/or material components. There are different types/processes of prototyping in various industrial sectors. Prototyping usually involves sequential tests of the design of relatively generic features of the final

product.

Computer modelling: this is a prototype designed and tested by computer software, not involving a physical artefact, but digitally simulating the expected features of the product. It is currently a common development activity in several engineering sectors.

Clinical trials: sets of tests in medical research and drug development that prospectively assign human participants to health-related interventions in order to evaluate their health outcomes (typically, drug effects and their safety).

Product certification: the documentation that a specific product has undertaken and successfully passed a series of performance tests indicating that the product in question complies with pre-determined criteria typically defined by regulations and/or (semi-)mandatory technical specifications set up by governments and/or standardizing bodies. Certification is conducted by certifying laboratories/ organizations usually of a semi-public nature.

The multiple types of development activities are performed by very diverse organizations. Sometimes these activities are conducted inside firms' own R&D labs whereas at other times they are outsourced to specialized external organizations/firms of typically private or semi-public nature. These organizations normally sell their services to companies or to governmental agencies and may sometimes enjoy (generous) state support for some basic costs. Most of the time they are specialized in some sectors (e.g. medical devices development, fire safety testing, or defence-related product development).

Traditionally these organizations have operated in their national/sub-national contexts. However, their activities have become more internationalized over the past decades, probably due to an accelerated internationalization of certification and standardization processes as well as cross-border regulations and trade agreements. These development-related organizations usually constitute crucial organizations that bridge the world of research and new knowledge production with the world of industrial application, commercial use and regulatory compliance. This bridging role must not be underestimated in an innovation system. This is particularly important for small and medium sized enterprises (SMEs) for whom access to specialized development competences and the necessary laboratory infrastructure and equipment would otherwise not be possible.

Seen from a perspective of innovation policy and investment portfolio approach, most of these development activities have tended to go under the radar of policy debates. Generally speaking, much

emphasis is typically put on the "research" side of R&D to the detriment of "development". The result of this is that this little brother has tended to remain under-examined and under-considered. This is a major paradox since innovation entails to a great extent the ability of an innovation system to be able to successfully conduct development activities. Furthermore, development activities form part of the policy-makers decisions related to the investment portfolio of public support to R&D. Section 7 looks at the deficiencies, tensions and problems of innovation systems in this respect.

6. Research Universities: A Top-Down Revolution

Universities are central organizations in any innovation system. There are however many different types of universities and many different ways in which national/regional governments interact with, regulate and fund their universities. In this chapter, we focus on universities where there is an important component of research activities and examine two key issues which are having a profound effect on universities, namely, the deep transformation of university roles and organization in some countries and the recent emergence of global university rankings.

The relative presence and weight of universities in innovation systems varies considerably from country to country. In some countries such as Sweden, the Netherlands or Canada, universities tend to perform between 25% and 30% of the country's overall R&D expenditure whereas this is much lower in other countries. This depends on the features of the innovation system and on the relative tradition of research universities (Mowery and Sampat 2005). In the USA, the very strong research-based universities grew from the turn of the 20th century (Geiger 2004) and have recently become an example for developments in this direction in Asia, Latin America (Altbach and Balán 2007), not least, Europe (McKelvey and Holmén 2009).

Over the last two decades, research universities have moved from a relatively unnoticed life outside public scrutiny towards being seen as core elements in the innovation performance of a national economy. During this period, universities have been seen as performing a series of different tasks (Uyarra 2010): the production of scientific knowledge (university as "knowledge factory"), the sharing of knowledge with firms ("relational university"), the commercialization of their research outputs ("entrepreneurial university"), the activities related to boundary spanning in the innovation system ("systemic university") and their active contribution to economic development in their local area ("engaged university"). These tasks and roles largely overlap and most universities have introduced significant organizational changes that meet these external demands and political expectations. These organizational changes are closely linked to the introduction of top-down reforms of university governance and the introduction of more competition-based R&D funding allocations to universities[3].

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[3]See Section 4 in this chapter.

Most of the university reforms in Europe, Asia and elsewhere have been guided by a national governments' wish to make universities strategic actors in the innovation system. However, their ultimate ability to become so largely depends on the overall framework of university governance in that country (Whitley 2008). More concretely, this refers to the extent to which universities exercise authority over their inputs and outputs (their levels of dependence on state funding, their discretion on resource allocation inside the university, the ability to employ directly or not their scientific staff and their ability to select students), as well as their ability to exercise authority over internal processes (discretion over establishing and closing departments, on promotion of scientific groups inside the university, on establishing research and teaching priorities and on defining their own performance goals and mechanisms to pursue them). In other words, their ability to become a strategic actor in the innovation system depends on their degree of organizational, regulatory and financial framework.

The recent reforms of university governance in some countries show a large degree of variation in scope and focus. This diversity reflects the different roles that research universities have traditionally exercised in innovation systems. However, most of these reforms are somehow linked to the social and political wish that universities are able to compete in a national and international context. This competitive zeitgeist can be observed in the second key feature examined here.

The second key feature of the recent and profound transformation in higher education is the remarkable thrust towards the detailed measurement of the quantity and quality of universities' research outputs. This measurement includes international publication data bases, the widespread use of citation analyses, the introduction of university and scientific discipline-level of peer review exercises, and perhaps the most politically visible of them all, the introduction of a large number of university rankings. Different countries have taken very different approaches towards this matter. In any case, the growing attention towards measuring university R&D performance has been equally prominent in developed and developing countries.

Some of these initiatives have been taken by governments in an attempt to make new incentive mechanisms based on performance. This is, for example, the case of public initiatives that aim at measuring cross-university performance. Perhaps one of the most far-reaching (and controversial) initiatives in this regard has been the Research Assessment Exercises (RAE) by the UK government (Hicks 2012). Other initiatives, however, have come from private (or non-governmental) organizations. This is the case, for example, of databases and software tools measuring and analysing scientific citations such as "google.scholar.com" or "Hartzing's Publish and Perish" software tools. These new entrants in the market of publishing and citation indexes have been game changers in the field providing free and easily accessible information to users and challenging incumbents.

Private initiatives in the field of higher education and research in the early 2000s have had a profound impact. This is particularly the case for university rankings. The publication in 2003 of the "Academic Ranking of World Universities" by Shanghai Jiao Tong University created a true wave of discussions about the quality of higher education worldwide. Since then, the number of university rankings has grown rapidly. Today, the most well-known rankings are produced by a series of private or semi-public organizations including the Shanghai Ranking Consultancy (SRC), Times Higher Education-Thomson

Reuters, Quacqarelli-Symmonds (QS), CWTS Leiden, Taiwan Higher Education Accreditation and Evaluation Council and the Centre for Higher Education Development/*die Zeit,* or Reitor, among others.

The European Commission and the OECD too have launched their own ranking projects, namely, the European Multidimensional University Ranking System (U-Multirank) and the Assessment of Higher Education Learning Outcomes Project (AHELO) respectively. Almost since the creation of all these rankings there have been growing criticism regarding several important aspects. The European University Association pointed to the fact that the rankings tend to be elitist, focusing only on the research-heavy, oldest and largest universities worldwide (European_University_Association 2011).

More problematic perhaps is the growing view that the methodologies of these rankings are not transparent (methodologies and data not - sufficiently - available) and use disputable data (i.e. self-reported data, lack of normalization of data). Sometimes the methodologies have changed rapidly, rendering virtually incomparable results of the same ranking through time (Hazelkorn 2013). Yet, regardless of these issues, it is obvious that the rankings have had tremendous impact. They have exposed higher education to international comparison and governments and university leaders alike have had to deal with them. It has been virtually impossible to ignore them, most probably because their comparative effects have caught the eye of the media and public debates.

7. Deficiencies, Tensions and Imbalances in the System and in Policy-making

After the previous sections' examination of the R&D investment portfolios and their returns, the recent trends in the public funding on research, the role of "development" in R&D activities and the organizational change of universities, we need to look at some of the possible deficiencies, tensions and imbalances in the innovation system. As mentioned above, knowledge production (and especially R&D) is performed in specific contexts. "Context" refers not only to the fact that the production of new scientific-technical knowledge offers new opportunities for innovation activities but also that innovation is highly related to the features and dynamics of the economy and society.

Three general sets of deficiencies, tensions and imbalances in the innovation system in relation to R&D activities seem to come to the fore from the previous sections. The first set has to do with **the insufficient and unbalanced levels of R&D activities in an economy and society.** As mentioned above, determining the levels of R&D is essentially a political (and hopefully also a democratic) process. Societies must explicitly define their own wishes with regard to their aspirations for economic growth and for other socio-political goals. From this point of departure, it can be useful to analyse the extent to which the levels of R&D activities in an innovation system are sufficient in fulfilling those goals.

Since the 1950s and 1960s, economists have argued that there is invariably an underinvestment in R&D activities by firms because knowledge is a public good and hence partly inappropriable (Nelson 1959, Arrow 1959/ 2002). Without questioning the public nature of knowledge and its associated

appropriability problems, our argument is that the overall levels of investment (or underinvestment) in an innovation system are essentially an issue of socio-political goals rather than a one-size-fits-all 'optimum' for all economies. Furthermore, the factors that generate R&D underinvestment may not just be the public nature of knowledge itself but far more complex factors, highly embedded in specific social and economic contexts. For example, if Spanish firms have underinvested in R&D activities in the period 2007-2014, this is most probably associated with a number of problems related to the severe economic and financial crisis (most crucially, the accessibility to capital and the brain-drain of highly skilled workers) than with the appropriability of knowledge as such.

The unbalanced level of different types of R&D activities is another important problem. For example, too much emphasis on "R" (research activities) in relation to "D" (development activities) may not have a positive effect on overall innovation performance. The overfunding of research (most typically public investment) is observable in some prestige projects where governments have funded research facilities, infrastructures and equipment, without considering the context (geographical, socio-technical and the like) in which that investment is made and without considering how this knowledge will be exploited in relation to "development" activities.

The notion that the more quantitative investment in research, the more innovation will automatically come out of it, is still widespread today. Sometimes, there is an overwhelming focus on increasing the level of public and private funding in research activities without much consideration for the less attractive but no less crucial "development" activities. Other forms of unbalanced investment levels in an innovation system have to do with differences in big and small science (or big & small research activities). Recent studies suggest that large publicly funded projects are proportionally less productive than small publicly funded projects (Fortin and Currie 2013). A similar issue may emerge between small and large firms' investment in R&D and their respective yields in innovation performance. Knowledge-intensive SMEs have traditionally been seen as relatively weaker compared with large knowledge-intensive firms. This particular concern is behind the creation of the SBRI program in the USA in the 1980s supporting small business research (Black 2006).

A second set of imbalances and deficiencies of R&D activities in the innovation system has to do with **the undefined goals of public R&D investment**. For many decades, the development of R&D public investment has been conducted within the parameters of very broadly defined political goals. Naturally, this is not a problem in itself. The problem, or more correctly, the deficiency, has to do with the lack of a systemic view in terms of the overall expected outcomes of such an investment. In particular, the strong emphasis on the fact that R&D activities purpose is to contribute to economic growth has somehow tended to put the focus on improving the aggregate level of private rates of return to those firms receiving public funds. We know from the discussions in this chapter that the social rates of return of R&D investment can at times exceed those of private returns due to spillovers (here including not only market benefits but also knowledge spillovers). However, public investment has not always focused on that. Sometimes it has just focused on increasing the aggregated levels of private returns. An example of the latter is the motto "from research to bill" (fraforskningtilfaktura) that dominated the Danish research policy in the early 2000s partly reflected that focus on the aggregate level of private rates of return rather than on the social rates.

Another deficiency in the innovation system has to do with time, or more concretely with the time lag between the decision to invest and the returns of the investment. As we have seen in this chapter, R&D activities require at times heavy investments, both public and private. In some areas, such as space research, biotech, or nanotech, the time lag between investment in research activities and their outcomes in terms of innovative outputs is extremely long and extremely uncertain. Moreover, it takes approximately 15-20 years to build up research environments in public research organizations or universities. This important time lag is an issue in terms of finding suitable capital (for private firms) as well as enabling a country to position itself in new emerging scientific and research areas and re-direct or re-orient R&D efforts in other (declining) scientific/knowledge and industrial areas. This time lag can be particularly problematic in times of financial constraints. As the financial and economic crisis since 2008 has clearly shown, some Southern European countries have disregarded the long-term effects of public R&D investments in favour of the short-term needs of cutting public expenditures. This (at times massive) discontinuation in public R&D investment may become very problematic for the future competitiveness of those economies. Furthermore, this will be aggravated by the brain drain of young researchers which will together represent a net loss of competences (skills and expertise) as well as R&D outputs.

These latest remarks bring to the fore the last, but not least important, third set of imbalances of R&D activities in the innovation system, namely, those that have to do with **problems directly related to policy-making**. In our industrialized societies (developed or developing), the role of public action is intrinsically embedded in the innovation system. This means that public action is today a reality and part and parcel of the innovation system as such. Therefore, when examining imbalances or problems in innovation systems, we can also refer to those that are related to the role of public action itself. Two such problems come to the fore. One problem has to do with a certain tendency to traditionalism in public R&D funding. This has to do with the observation that, in spite of political rhetoric, sometimes public R&D support programs are not designed in a way that promotes the most cutting-edge or novel type of knowledge production. Continuity of research funding lines, logics and targets, may secure stability in the funding of R&D environments (universities, public research organizations or firms). The extent to which that continuity is positive for the overall innovation system depends very much on the ability of these environments to generate R&D outputs that are significant and valuable assets for the innovativeness of the economy. This is what economists have referred to as the "technological lock-in" in innovation systems which is not only a matter of firms' own investment decisions but also the inability of public R&D investment to break such negative lock-in dynamics.

The second type of problem associated with public R&D investment in the innovation system has to do with the unbalanced and somehow unsophisticated use of indicators and performance measures of R&D outcomes. The quantitative measurement of R&D and innovation activities has improved dramatically over the past few years (Moed, Glänzel et al. 2010). The creation of new databases and new measurement methodologies had revolutionized the fields of research evaluation and the comparative studies of national innovation systems (Schmoch, Rammer et al. 2006). Today we have a much more empirically-based analysis of innovation systems, their dynamics and their comparative performance. In spite of this, policy-making tends sometimes to be based on rather simple measurement techniques that

do not reflect sufficiently well the complexity of factors that interplay in the performance. This is, for example, the recent case of university rankings. Some of these university rankings use inconsistent methodologies across time (making them unsuitable for comparison across time), use partly self-reported data by universities (with all the reliability problems that this represents) and lack theoretical foundations behind the specific weighting of variables in their aggregate indexes. In spite of these severe problems, university rankings are extensively used today in the public domain as comparative indicators of quality. However, their methodological inconsistency, data unreliability and a theoretical character make them problematic. If taken too seriously, these rankings may induce poorly-considered policy action and public R&D investments.

8. Conclusions: Criteria for Designing R&D Funding in Innovation Policies

The production of knowledge, and in particular R&D activities, is an essential part of an innovation system. After defining on a general level the role of knowledge and of R&D activities in the innovation system and the related conceptual clarification, this chapter has examined four specific areas, namely, R&D investment returns, the recent trends in public research funding, the relevance of "development" activities in the innovation system and the profound transformations of research universities over the past few years. These considerations have been the backbone for the identification of a series of general types of deficiencies, tensions and imbalances in the system and policy-making in R&D.

This section examines the lessons of these previous issues in relation to the design of innovation policy. In particular, it aims to identify and develop a series of criteria for such design. Traditionally, economic approaches in the 1950s and later have focused on two rationales for public R&D expenditure, namely, the additionality of public R&D expenditure vis-à-vis private expenditure (or its non-substitution effect over private expenditure) and the need to introduce public regulation to secure the appropriability of knowledge production by firms conducting R&D activities, as a way to overcome the lack of incentives in the market due to the public nature of knowledge. In this chapter we do not aim to discuss these traditional theoretically-deduced rationales. Instead, we aim to put forward a set of criteria for the design of innovation policy that is based on empirical observations and on the analysis of the deficiencies, tensions and imbalances in R&D activities. Hence, our perspective is not so much based on theoretical considerations concerning the nature of knowledge but rather on the real context in which knowledge and R&D are being produced and used. In so doing, we aim to present a more realistic picture of the actual and direct problems associated with R&D activities and the dilemmas and challenges that policy-makers currently face when making decisions regarding the allocation of public budgets and the organization of R&D activities in the system.

As expressed earlier, our point of departure is the understanding that R&D is not an expenditure but an investment and policy-makers must therefore consider the distribution of this investment portfolio according to the different types of investments (long-short term, high-low risk and results). This also

means that governments must examine the private and social rates of returns of this public portfolio investment. All in all, the investment portfolio approach means a perspective where policy-makers are able to set targets and goals for what is expected from public investment in R&D. Before setting such targets, policy-makers must take into consideration the current imbalances, deficiencies and tensions in their innovation systems and design their policies accordingly. In particular, they must look carefully at three large sets of issues, namely, the balance between R&D activities in the economy and society, the goals of public R&D investment and the problems directly related to policy-making.

The following criteria emerge from the above discussions:

Innovation policy must secure adequate levels of private and public investment in R&D (according to politically defined goals). Innovation policy must secure the diversity of knowledge production and R&D activities and a certain balance between different types of R&D activities, namely "research" and "development" and between knowledge-intensive large and small firms as well as large and small collaborative R&D projects.

Public R&D investment must focus primarily on enhancing the social rates of return in an innovation system. This is because policy makers must be aware and encourage processes of knowledge spillovers while securing certain levels of appropriability. Since appropriability will invariably be imperfect, policy-makers must be attentive to the positive spillover effects of knowledge production in a system to a point where private incentives to invest in R&D are not undermined.

Public investment in R&D must be risk-taking. We know that the return on investment in R&D is skewed due to the high levels of unpredictability of R&D investments. This gives policy makers leeway to think strategically, designing policy in a way that takes into account the unavoidable skewness of any such investment return. The risk of public R&D investments, however, must never reach a "systemic risk level". That would jeopardize the entire innovation system and its future dynamism.

Public investment must be patient. We know that there is a large time lag between public (and private) decisions to invest and the returns thereof. This is actually part of the risk that public action must be willing to take. However, such patience must not be blind. Policy-makers must define guideposts and milestones regarding the performance of that investment along the way.

Adaptable public funding on R&D. Policy-makers must avoid problems of lock-in in the investment of specific scientific and industrial areas. They must also avoid excessively rapid changes and inconsistent policy targets because it takes at least 15-20 years to build strong research groups. Hence, policies must strike a balance between problems of institutional inertia and interest capture in R&D areas of investment and too rapid a change in focus which results in insufficient public investment.

Last but not least, **R&D investments and organizational public decisions must be based on intelligent and reliable-data based performance measurements of the innovation system**, not least for universities (avoiding the misuse of unreliable university rankings and other simplistic benchmarking exercises).

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