Journal of Economics Library
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Volume 5 March 2018 Issue 1

Evolution of the economics of science in the Twenty Century

By Mario COCCIA [†]

Abstract. A new discipline analyses the role of science in society: the economics of scientific research. The purpose of this paper is to investigate the origins, nature, evolution and structure of the economics of scientific research. The paper suggests that one of the first scholars that has tried to systematize this discipline is Paul Freedman with the book "The principles of scientific research" published in London in 1949 by Pergamon Press. In addition, the study here also endeavours to show whenever possible the evolution of this discipline through central topics from emerging research fields.
Keywords. Science, Scientific research, History of science, Evolution of Science, Research policy, Research laboratory, R&D management.
JEL. B20, D80, L30.

1. Introduction

Interest in the role that scientific research play in economics and the other social sciences has exploded in the last thirty years. This increased attention undoubtedly reflects the increased importance that scientific research is contributing to technological development, and as a consequence, employment and economic growth in Europe, North America and Asia (Romer, 1994; Porter, 1988)[i]. In response to this increased policy focus on science, scholars have generated a wave of studies and inquiry focusing on the economics of scientific research and innovation. While this new literature has its roots in classic articles written, in some cases, nearly half a century ago, it has the special characteristic of spanning a number of fields, not only within economics (such as labour economics, industrial organization, innovation and technological change, economic history, and even growth theory), but also other social sciences such as sociology, psychology and the management of technology. The field demands an understanding not just of economic and social forces but of scientific developments as well. The wide range of scholarly disciplines involved in research on the economics of science and scientific research has made it difficult for scholars in any one field to grasp the research contributions and to offer courses, at either graduate or undergraduate level, on the economics of science and of scientific research. Although the field has much older roots, the contemporary basis for the subject solidified when the *Journal of Economic Literature* invited Paula Stephan to summarize what is known and not known about the economic analysis of science. Her response was *The Economics of Science*, which was published in the *Journal of Economic Literature* in 1996. Stephan (1996, p.1199) introduces the subject:

> Science commands the attention of economists for at least three reasons. First and most important, science is a source of growth. The lags between basic research and its economic consequences may be long, but the economic impact of science is indisputable. Second, scientific labor markets - and the human capital embodied in scientists - offer fertile ground for study. Third, a reward structure has evolved in science that goes a long way toward solving

[a†] Arizona State University, Interdisciplinary Science and Technology Building 1 (ISBT1) 550 E. Orange Street, Tempe- AZ 85287-4804 USA.
☎. + 85287-4804
✉. mario.coccia@cnr.it

the appropriability problem associated with the production of a public good.

Despite the remarkable efforts made in the twentieth century, works attempting to deal with economics of research and science (Martin & Nightingale, 2000; Stephan & Audretsch, 2000; Garonna & Iammarino, 2000) do not yet have clear outlines, because it is easy to find in them subject matters concerning innovations that pertain to other sciences and/or disciplines. Furthermore, within the economic literature there is often a certain degree of confusion about the terms ‘science’ and ‘research’, commonly used as if they were synonyms, even though the two concepts are actually different. In view of such issues, the purpose of this article is to analyse, within the history of economic thought, the origins, nature and structure of the branch of economics defined as economics of scientific research. This is also useful to clarify the terms science, research, scientific research and their related taxonomies. In order to do so, section 2 analyses such topics, drawing attention to what can be considered the first definition of scientific research. After having highlighted the origins and nature of this important branch of economics, section 3 points out the main features of the discipline’s structure, on the basis of numerous fields of research present in scientific journals. The last section of the paper focuses on some concluding remarks.

2. Origins, nature and evolution of the economics of scientific research

The paper analyses the nature of scientific research, a type of research associated to science. Although there have been several contributions to this field of investigation in the last few years, the origins of this discipline can be traced back to classical economists. In fact, in the 1800s, when analysing economic phenomena and addressing subjects related to scientific research, several scholars referred to the terms science, philosophy, technology, invention, and so on. One of the first scientists who dealt with such topics was Francis Bacon[ii], who believed that science had the power to improve the society’s economy and standard of living. In his work *New Atlantis* (1629), he saw science, technology, politics, industry, and religion as deeply intertwined. Bacon is important because he was one of the first to suggest a link between organisation of science and economic progress. Bacon’s work marked the beginning of a new way of thinking about the science. Since scientific research derives directly from science, in order to define the former, first of all it is best to clarify the concept of science.

The term science has been given different meanings by scholars. The great Scottish economist Rae (1834) maintained that:

> It is indeed true that the philosophy, in the introduction of which he bore so eminent a part, has, in these latter ages, been a very effective promoter of the dominion of man, and, mixing with art, has much purified and dignified its spirit, and greatly increased its powers, turning invention in this department from particulars to generals, and converting art into science. This has more especially happened in the chemical sciences, and those connected with them, a sphere to which, I may be allowed to observe, his system seems particularly applicable. There, science begins to lead and direct art; in other departments she rather follows and assists it… the aim of science may be said to be, to ascertain the manner in which things actually exist (Rae, 1834: 254).

Dampier (1953) provided one of the most prominent definitions of science and stated that:

> Ordered knowledge of natural phenomena and the rational study of the relations between the concepts in which those phenomena are expressed.

Russell (1952) gave a broader definition:

> Science, as its name implies, is primarily knowledge; by convention it is knowledge of a certain kind, namely, which seeks general laws connecting a number of particular facts. Gradually, however, the aspect of science as knowledge is being thrust into the background by the aspect of science as the power to manipulate nature.

According to Paul Freedman (1960) the definition of Bertrand Russell is the more satisfactory, while Dampier's definition relates only to scientific knowledge, and does not take into account either the application of such knowledge, or the power to apply it, towards control and change of man's environment. But though wider than Sir William Dampier's definition, Russell's definition is also open to a serious objection. It presents science as static, whereas it is intensely dynamic. The most important attribute of science is not knowledge, but its capacity for acquisition of knowledge. Knowledge which science contains is limited, frequently fragmentary and inaccurate, always liable to revision. The capacity of science to acquire knowledge is infinite. A different definition of science was provided by Crowther (1955), according to whom:

> Science is a system of behaviour by which man acquires mastery of his environment.

Alessandro Volta (1792)[iii] put forward a concept of science that has its greatest and most rewarding moments in practical activity, but at the same time is somehow limited in the creation of a theoretical framework. For the Italian scientist, science is invention and it is characterised by the scientist's specific aptitude for the construction of devices and artefacts. Therefore, Volta interpreted the concept of science in an experimental sense. On the other hand, Thomas Kuhn (1969) claimed that:

> Science is a constellation of facts, theories, and methods… Hence scientific development is the fragmentary process through which these elements have been added, singularly or in groups, to the ever growing depository that constitutes technical and scientific knowledge.

Kuhn (1969) also talked about normal science, i.e. research that is firmly based on one or more results previously achieved by science.

Thus it may be seen that an adequate definition of science is difficult to frame. A perfect definition of science is, indeed, an impossibility, since an understanding of the nature of science, like science itself, changing with the passage of time, can only gradually approach to truth. An adequate definition of science must be wide enough to include all its aspects and, at the same time, rigid enough to exclude all that is no-scientific in reasoning, knowledge, experience and action. It must, while excluding activities, which are merely a haphazard accumulation of empirical knowledge and practice (like culinary and fashion art), include not only all the pure but also all the applied branches of science. An adequate definition of science, while excluding all practices of essentially magical nature, must include all genuine science even in its very early stages, however elementary and naïve. It must not only present science as dynamic, but take into account the fact that nature itself is not static, and that its laws are not immutable but change with time (Freedman, 1960). A definition that satisfies the above conditions is the following:

> Science is a form of human activity through pursuit of which mankind acquires an increasingly fuller and more accurate knowledge and understanding of nature, past, present and future, and an increasing capacity to adapt itself to and to change its environment and to modify its own characteristics (Freedman, 1960).

Brevity is essential to any definition. Consequently, no definition can give an exhaustive presentation of that which it defines. Its essential brevity is achieved at the cost of omission. After the definition of science, we focus on the concepts of research and scientific research.

"Research" in all fields of human activity means continued search for knowledge and understanding. *Scientific research differs from other kinds of research in that it is a continued search for scientific knowledge and understanding by scientific methods.* This dual determination of the scientific nature of a research - determination by objective and by method - is of fundamental importance. Not all knowledge and understanding is scientific and if anyone were foolish enough to search for the best spinet music or for understanding of a poem by scientific methods, he would not, in any sense, be engaged in scientific research. Knowledge and understanding of movements of heavenly bodies would, on theother hand, be scientific knowledge, but anyone searching for such knowledge by unscientific methods, for example by study of theological works, would, most certainly, not be engaged in scientific research. The meaning of the expression "scientific knowledge and understanding" follows naturally from the definition of science (Freedman, 1960).

Scientific research is not as old as science because scientific knowledge and understanding were impossible until the time when science reached a certain level of development that enabled to conceive the scientific method. John Rae (1834) said that:

> In the ancient world, science, as founded on a generalization of the experiences of art, was little prosecuted. It is only in modern times, that the science of experience has come to form an element of importance, in the general advance of invention.
>
> It is clearly on the antecedent progress of art, that the foundation of the hopes of Bacon, for the future progress of science, rested. His philosophy may be fitly described, as a plan to reduce to method the chance processes that had been going on before, by which men, as we have seen, happening on one discovery after another, grope their way, as he expresses it, slowly, and in the dark, to fresh knowledge and power. The progress of the philosophy to which he has given his name, as well as that of the science of mathematics, have unquestionably discovered to us many general truths, and theorems of art, and form therefore a new element influencing its progress. The great moving powers will, however, still, I apprehend, be found to proceed from the principles, the action of which we are now to attempt farther to trace through particular instances ... (p. 240).

The prodigious development of many sciences and technologies is pushed by the application of two scientific methods[iv]:

- *inductive*, which starts from the experimental observation of phenomena and traces back the laws that regulate them by means of experiments, analogies, and hypotheses;
- *deductive*, which starts from the theory and the general ideas in order to predict new laws and therefore discover new phenomena.

The development of the experimental method was refined by Lazzaro Spallanzani[v] and consisted in varying incidental and environmental circumstances, to the point that it would be possible to almost completely eliminate all the interferences due to these factors. Scientific research, deriving from the application of these two procedures, is divided into two important fields (Godin, 2001): basic research and applied research.

Basic research was first defined explicitly in taxonomy in 1934 by Julian S. Huxley and later appropriated by Vannevar Bush[vi] (1945), while Cohen originates the concept of pure research in 1948. Philosophers distinguish between science or natural philosophy, that is motivated by the study of abstract notions, and the mixed "disciplines" or subjects, like mixed mathematics, that are concerned with concrete notions (Kline, 1995). Basic research came into regular use at the end of the nineteenth century and was usually accompanied with the contrasting concept of applied research. In the 1930s, the term “fundamental” occasionally began appearing in place of "pure". The first attempts at defining these terms systematically occurred in Britain in the 1930s, more precisely among those scientists interested in the social aspects of science. Bernal[vii] used the terms "pure” and "fundamental" interchangeably. Huxley (1934), who later became UNESCO's first Director-General (1947-48), introduced and suggested the first formal taxonomy of research. The taxonomy had four categories: background, basic, ad hoc and development. For Huxley, ad hoc meant applied research, and development meant more or less what we still mean by it today. Frascati manual (OECD, 1968), instead, distinguishes among: **Basic research** is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts *[epistemological- general / reductionist]* without any particular application or use in view *[intentional]*. **Pure**

basic research is carried out for the advancement of knowledge without working for long-term economic or social benefits and with no positive efforts being made to apply the results to practical problems or to transfer the results to sectors responsible for its application *[intentional]*. **Oriented-basic research** is carried out with the expectation that it will produce a broad base of knowledge *[epistemological-general]* likely to form the background to the solution of recognized or expected current or future problems or possibilities *[intentional]* (Calvert, 2004).

As Joseph Needham (1959) says, there is no sharp distinction between "pure" and "applied" science - "There is really only science with long term promise of application and science with short term promise of application. True knowledge emerges from both kinds of science".

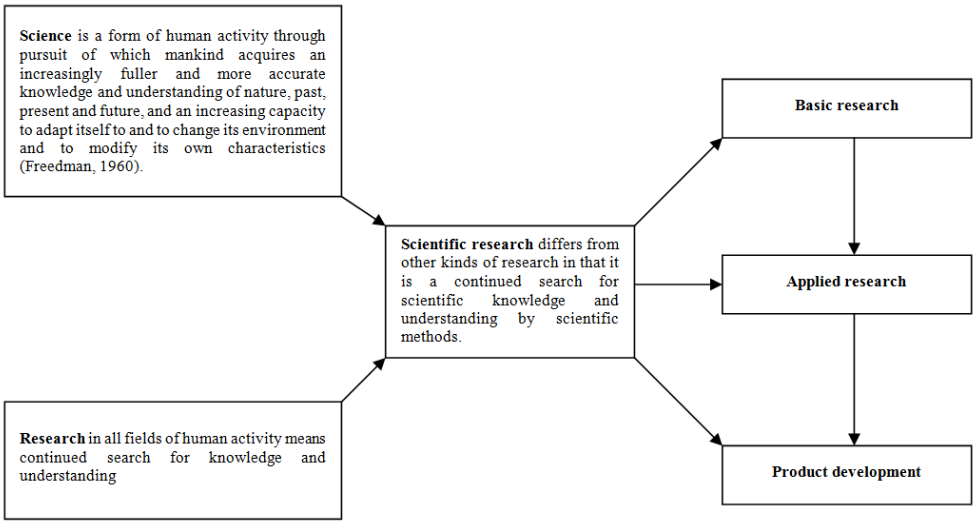

Figure 1. *Derivation of scientific research and its taxonomies*

One of the main outputs of the scientific research process is invention, which is often dealt with in books that talk about the economics of scientific research. Inventions can be divided into autonomous and induced. The first type is the long-term contribution of a casual genius who, by applying intuitive ideas to existing technologies, increases the set of technical knowledge. This is the type of invention investigated by Rae (1834) and widespread during the Renaissance that took place in European culture during the fifteenth and sixteenth centuries, when researches were commissioned to scientists (such as, Leonardo Da Vinci), who were financed by rich patrons. Induced invention, instead, is the deliberate use of time, resources, and efforts in order to promote new technical knowledge. This type of invention is created in Research and Development (R&D) laboratories and is the most common form of research in the modern age (Nelson, 1962).

Once scientific research and its typologies had been defined, the discipline dealing with its study, the "economics of research", started to make headway and to develop as an autonomous field of investigation in post-war times. Scientific and technical advances have always been important to military success, from the mass production of Springfield rifles in the American Civil war, to information, telecommunications and electronics in the Iraq war. Bernal (1939), writing between the two World Wars, was not optimistic about science. Barnal's work explicitly recognises the lack of direct link between social and scientific progress. During the Second World War, research began to be carried out mainly in corporate research laboratories, organisations having a staff of scientists with homogeneous and/or heterogeneous training and education. In fact, the scientists involved in the Manhattan project established one of the first research laboratories. The United States initiated this program under the Army Corps of Engineers in June 1942.

Italian physicist Enrico Fermi managed the University of Chicago reactor, called Chicago Pile 1, and under the abandoned west stands of Stagg Field, the first controlled nuclear reaction occurred. The project had military purposes and led to the first atomic weapon. At the end of the war, alongside military research, laboratories began to conduct researches for civil purposes, above all focusing on the production of electric power. The project's conversion to different aims led to the creation of a series of laboratories in the United States, which are still renowned today for their advanced researches, for example the Sarnoff Corporation (http://www.sarnoff.com/) and the Los Alamos National Laboratory (http://www.lanl.gov). It was the success of the Manhattan Project that symbolised the power of big science projects involving governments, scientists, industrialists and universities. Moreover, it was on May 14, 1948, that project *RAND*-an outgrowth of world war II-separated from Douglas Aircraft Company of Santa Monica, California, and became independent, non-profit organization. Adopting its name from contraction of the term *research and development* the newly formed entity was dedicated to furthering and promoting scientific, educational, and charitable purpose for the public welfare and security of the United States. By early 1948, Project *RAND* had grown to 200 staff members with expertise in a wide range of fields including: mathematicians, engineers, economists, chemists, physics, aerodynamicists, and so on. For Bush, this success established a linear model from: *basic physics→large scale development→applications→military and civil innovations.*

The presence of laboratories made it possible to collect large series of data but it also brought policy makers face to face with the first issues regarding financing and effective management of organizations, whose main aim is the production of scientific research, which is beneficial for society and its wellbeing. Bush's view, that science should be publicly funded and left to itself in order to produce advances in technology, was influential on the post-war research policy in a period of economic growth. De Solla Price (1965) recognises the interaction between science and technology and uses the metaphor of two dancing partners who are independent but move together. These features together with specific historical circumstances related to the World War led to the birth and development of the economics of research. While the Stephan (1996) provides a contemporary view of science, we, go back to 1959 for the article *The Simple Economics of Basic Scientific Research*, Richard Nelson to trace some of the fundamental economic analyses concerning science that provide the basis of our modem understanding. However, the first scholar who really dug wholeheartedly into what, by any reasonable interpretation, can be called Economics of Scientific Research was Paul Freedman (1960) with is work *The principles of scientific research* published in London in 1949 by Pergamon Press Ltd. This remarkable work and author, and his treatment of economics of scientific research in particular, certainly deserve a scholarly study in its own right. Although today largely forgotten, the role of his 1949 book could from the point of views of economics of science and research to be considered to correspond to the role of Smith's "The wealth of nations" in general economics. After Freedman's book, around the 1950s, contributions to the economics of research became more and more numerous, so much so that today there are several journals that deal with its issues. Among them, some of the most prominent are: "Minerva: A review of science, learning, and policy" (established in 1962) by Springer; "Social Studies of Science: An international review of research in the social dimensions of science and technology" established in 1970 edited by Michael Lynch Editor; "Prometheus" edited by Routledge; and others that deal with more specific topics, as will be explained in the next sections.

Figure 2 places the beginning of the modern branch of the economics of scientific research around the 1940s, when the Second World War led to the institution of the first organised laboratories for the production of scientific research. In particular, the first edition of Freedman's book, dated 1949, can be considered to mark the date of birth of this discipline. Figure 2 also displays, in chronological order, the main contributions of economic literature that have helped the development of this field of investigation and that are described in the following section.

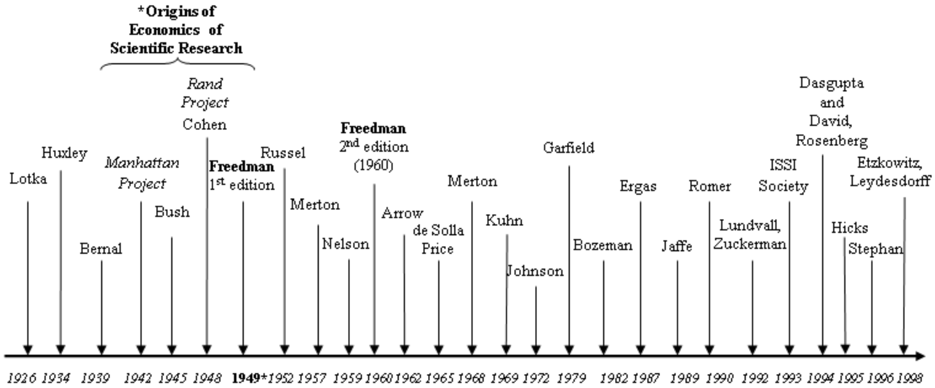

Figure 2. *Origins and evolution of the economics of scientific research and main contributions*

3. Structure of the discipline

The content of the Book of Freedman (1960) is the following: part I presents the development of the process of research and its relationship with social change and available techniques; part II is the principles of the research process: types of problems, methods of attack, and essential disciplines (The mental approach to the research; the planning of research, the organization, the accuracy and economy of effort and the minimum number of essential observations). Part III is focused on the support available for research.

Since 1950s, several contributions (Stephan & Audretsch, 2000) have developed to the economics of the scientific research and the modern structure of the economics of scientific research could be based on the following central topics comprising the emerging fields: 1) The public nature of scientific research and financing; 2) Reward structure of scientific research; 3) Scientists and careers in scientific research; 4) Technology transfer and commercialization; 5) Knowledge spillovers; 6) Scientometrics and R&D Evaluation; 7) National and regional system of innovation and scientific knowledge; 8) Managerial and organisational behaviour of R&D laboratories; 9) Research policy; 10) Scientific research and economic growth.

- *The public nature of scientific research and financing.* The public nature of scientific knowledge appeared in the economics literature (Johnson, 1972), with the publication of Arrow (1962). He argues that within economic systems there are some goods that the markets either do not offer at all or do not offer in sufficient amounts. The public nature of science is based on the asymmetric appropriability of knowledge: subjects that bring about innovation generate social benefits that are not compensated by privately appropriable benefits. Within this neoclassical theoretical framework, public interventions in the scientific sector as well as the creation of remedies to the public nature of science are justified. The latter is done by means of patents, granting the exclusive use of knowledge for a limited period of time to those who have made a new discovery (Nordhaus, 1969). In view of the features mentioned above, an economic system based essentially on private agents, focused on maximising profits, would generate market failures, since private incentive does not make it possible to achieve a social optimum. In this sense, public financing bridges the gap between private investment and social optimum. Nelson (1959) justifies public aid to science with the inefficiency of the market of scientific knowledge. Callon (1994), by contrast, argues that the public nature of science is greatly overstated. He emphasises the tacit knowledge (Polanyi, 1966) can be more costly to learn than knowledge that is codified. Eisenberg (1987) states that publication of results is not equivalent to making the discovery a public good. Dasgupta & David (1994) argue that research findings become a public good only when they are codified in a manner that others can understand. They make an important distinction between knowledge, which is the product of research, and information, which is the codification of knowledge. They also argue the implications for appropriability and disclosure, that differentiate science from technology: 'If one joins the science club, one's discoveries and inventions must be completely disclosed, whereas in the technology club such findings must not be fully revealed to the rest of the membership' (Dasgupta & David, 1987, p. 528).

- *The reward structure of scientific research.* Merton (1957) argues that the goal of scientists is to establish priority of discovery by being the first to communicate an advance in knowledge, and that the rewards to priority are the recognition awarded by the scientific community for being the first. Zuckerman (1992) estimates that, in the early 1990s, around 3,000 scientific prizes were available in North America alone. This is the five times the number available two decades earlier. Stephan & Levin (1992) and Stephan & Everhart (1998) argue that scientists are interested in three types of rewards: 1) the puzzle, the satisfaction derived from solving a problem; 2) the ribbon, the recognition awarded priority and the prestige that accompanies priority; 3) the gold, the economic rewards that await the successful. Dasgupta & Maskin (1987) and, Dasgupta & David (1987) argue that there is no value added when the same discovery is made a second, third, or fourth time. To put sharply, the winning research unit is the sole contributor to social surplus. A defining characteristic of the type of winner-take-all contests analysed is inequality in the allocation of rewards. Scientific research has extreme inequality with regard to scientific productivity and awarding priority.
- *Scientists and careers in scientific research.* The first research on the frequency distribution of scientific productivity is by Lotka (1926). Levin & Stephan (1991), instead, analyse the productivity of scientists during their scientific life cycle, while other studies confirm that scientific productivity is asymmetrically distributed throughout the population of researchers (Allison & Stewart, 1974; David, 1994; Fox, 1983). In fact, a study by Ramsden (1994) about 18 Australian universities shows that, over a 5-year period, 14% of the total number of researchers produced 50% of the publications, while 40% of researchers produced 80% of publications. The explanation for the high productivity of some researchers derives from cumulative learning processes, among which the Matthew effect (Merton, 1968). This shows how researchers who accomplish prominent results at the beginning of their scientific career have an initial advantage over others and increased chances of obtaining further financial support as well as of accomplishing further discoveries[viii].
- *Technology transfer and commercialisation.* Technology transfer (Coccia, 2004; Coccia & Rolfo, 2002) can be considered as a flow that moves technology (or knowledge in general) from the source (public and private research bodies, universities, etc.) to the users (firms producing goods and services), during a certain time period, by means of provided channels (e.g. communication, logistic, distribution channels). Due to the relevance of technology transfer within the development of economic systems, this phenomenon has been widely studied, which has led to establishment of specialised journals, such as: *Journal of Technology Transfer* of Kluwer Academic Publishers and *International Journal of Technology Transferand Commercialization* born in 2002 by Inderscience publishers.
- A main aspect of the scientific research is the *Knowledge Spillovers.* Griliches (1992) explains what knowledge spillovers are, why they are important economic phenomenon, and how they can exist. Jaffe (1989) identifies knowledge created in university research laboratories as an important source of knowledge spillovers. Acs *et al.,* (1994) and, Audretsch & Feldman (1996) provide evidence that large firms are the recipient of knowledge generated in private research laboratories, while small firms benefit more from knowledge spillovers generated

at university and public research laboratories. Zucker *et al*., (1998) examine the spillover process and stress the importance of identifiable market exchanges between "Star" scientists and firms.

- *Scientometrics and R&D evaluation.* The assessment of scientific output involves the calculation of indices indicating the production, productivity or impact of research groups (Geisler, 2000). A basic assumption underlying this approach is that scientific progress is made by scientists who group together to study particular research topics and build upon earlier work of their colleagues (de Solla Price, 1963; 1965). In this way, an international community of scientists comes into being, who keep each other informed of results, which need to be published and submitted for evaluation to professional colleagues (Merton, 1972). The production is measured through the number of publications published by scientists in a group. The productivity measure relates his number of publications to the research capacity of the group, which is normally expressed by the number of full time equivalents spent of scientific research (Luwell *et al.,* 1999). Finally, the impact is indicated by indices based on the number of times the publications are cited in some 3,500 international scientific journals covered by the Science Citation Index (SCI), produced by the Institute for Scientific Information (Garfield, 1979). In the bibliometric assessment of technological output, data derived from patents play an important role (e.g., Narin & Olivastro, 1988; Griliches, 1990; Pritchard, 1969). The technical forms of bibliometric analysis are (Broadus, 1987): *Publication counts*; *Citation counts*; *Co-citation analysis* (Small & Griffith, 1974; Tijssen & Leeuw, 1988); *Co-word analysis*, developed in the early 1980's, involves the assigning of keywords to a paper or article by professional readers (Callon *et al.,* 1983; Mullins *et al.,* 1988; Rip & Courtial, 1984); *Scientific mapping* (Healey *et al.,* 1986; Rip, 1988); *Citations in patents* (Collins & Wyatt, 1988). The bibliometric analysis of the field gives rise to a number of problems. Several works of great relevance become common heritage and are, therefore, referred to without specifically quoting them. Moreover, many quotations can be critical rather than positive. Different scientific fields are fostered by groups of different sizes, therefore the chance of being quoted varies greatly from one field to the other. Besides, the value of a scientific work is not always known to its contemporaries (Sirilli, 2000). Other models evaluate the scientific performance of research organizations using combinations of various indicators as well as discriminating analysis techniques (Coccia, 2001; 2004a). Several contributions to this important area of research have been published in two international journals: *R&D Management* by Blackwell publishers, *Research evaluation* (established in 1992) by Beech Tree Publishing and *Scientometrics* (established in 1984) byKluwer Academic Publishers. Moreover, at the International Conference on Bibliometrics, Informetrics and Scientometrics held in Berlin, 11-15 September in 1993 was founded the International Society for Scientometrics and Informetrics. The Society aims to encourage communication and exchange of professional information in the field of scientometrics and informetrics, to improve standards, theory and practice in all areas of the discipline, to stimulate research, education and training, and to enhance the public perception of the discipline. The advancement of the theory, methods and explanations through two main streams: Quantitative Studies, Mathematical, Statistical, and Computational Modelling and Analysis of Information Processes.

- *National and regional system of innovation and scientific knowledge.* The elements that generate and spread knowledge throughout a certain area have been analysed using various approaches, starting from the basic National Systems of Innovation (NSI). Lundvall (1992) was the first scholar to include not only organisations directly involved in the innovative process but also all the aspects of the institutional structure that influence learning, accumulation of knowledge, and the search for all new discoveries. Lundvall's interpretation can be applied, with due adaptations, also to regional and pluri-regional contexts (Braczyk *et al.*, 1998). De Vet (1993) and Ohmae (1995) maintain that, by increasing its degree of globalisation, the economic system pushes interactions among firms into specific sectorial cluster on a more and more regional level. According to a further theoretical elaboration, the complex network of individuals and organisations operating within an innovative system can be described using the model of the *triple helix* (Etzkowitz & Leydesdorff, 1998; 2000). This model brings together three different entities – public research, firms, and the government – which in the past used to be much less integrated or simply associated two by two. Leydesdorff & Etzkowitz (2003) maintain that the public sector can be considered as an element constituting the fourth helix.

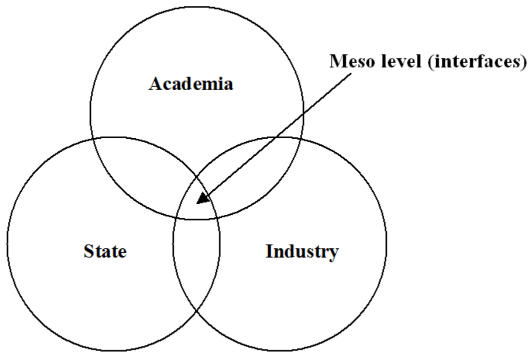

Figure 3: *Model of the triple helix describing the relations between Universities/Public Research Bodies – Industry/State. Source: Etzkowitz & Leydesdorff, (1998).*

❑ *Mangerial and organisational behaviour of the R&D Laboratories.* The public sector research is, according to Senker (2001), defined as civil research in institutions for which the major source of funds is public, which are in public ownership or control and which aim to disseminate the results of their research, i.e. the defense research is excluded. Among the entities involved in the production and transfer of scientific research, there are research laboratories and interfaces. Research laboratories are systems that produce goods and services by means of inputs, production processes (of the scientific activity), and outputs (Coccia, 2001), which are absorbed by the users within the economic system, in order to achieve higher competitiveness of the national industrial system, higher social wellbeing, the fulfilment of one's needs, etc.

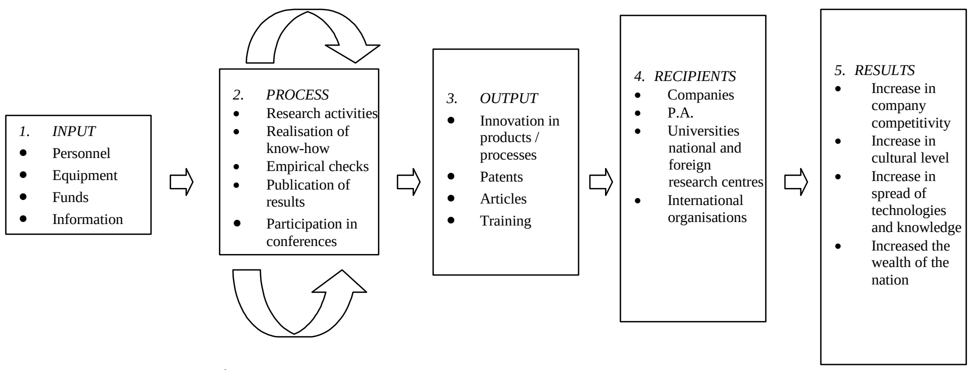

Figure 4. *The production system of research bodies.*
Source: Coccia, 2001.

1. Interface subjects (originated from the intersection of the three sets of the triple helix model) are considered as communication channels that facilitate scientific knowledge transfer from the source to the users by means of resource aggregation (for example, Science and Technology Parks). They also facilitate the meeting of supply and demand of innovations, as seen with Liaison Offices or Offices of Technology Transfer, whose purpose is to *enhance the development and* *value of University innovations by protecting them and linking them to marketable products and services*. Other studies have tried to elaborate a framework for understanding the structure and behaviour of laboratories that also provides a basis for rationalizing public science and technology policy in order to create laboratories that are more effective. Among the most relevant contributions are those by Bozeman (1982), Bozeman & Crow (1990), and Crow & Bozeman (1998), whose studies focus on research laboratories in the United States, while Coccia's papers (2001, 2004; 2004a) deal mainly with the analysis of Italian public research laboratories.

- *Research and science policy.* A wide overview of research policies in developed countries (Rosenberg, 1994) was drawn up by Ergas (1987), on the basis of the structural features of each national background. The two most relevant types of policies are *mission oriented* and *diffusion oriented*. The former (adopted by the US, UK and France) aims at gaining international leadership by shifting the frontiers of technological possibilities (*technology shifting*), a purpose which is achieved by means of researches targeting radical innovations, supported by high investments in Research and Development for the military sector. *Diffusion oriented* policies (adopted, for example, by Italy and Germany) aim at the so-called *Technological deepening* or movement within the frontier, i.e. scientific research focusing on incremental innovations. These policies are intended to improve the ability to absorb technologies and their commercialisation, by means of funds to secondary education and universities. Justman & Teubal (1996) use the concept of *Technological Infrastructure Policy* (TIP) and consider the public supply of scientific and technological skills as the main element capable of triggering the development of a region and of its industrial sector. This is made possible thanks to the action of the interfaces, which support integration with the sources of knowledge. *Science and public policy* (1974) by Beech Tree Publishing and *Research policy* (1971) by Elsevier are two of the main journals in which papers on this topic are issued.
- *Scientific research and economic growth.* The endogenous growth theory is one of the most prominent developments of research within the macroeconomic field (Nelson & Romer, 1996). Two scholars have greatly contributed to the success of this area of investigation: Romer (1990; 1994), of the University of California, and Lucas (1988), of the University of Chicago. However, cues to this field of research also came from 1970s works by Arrow (1962), of Stanford University, and Uzawa (1965), of Tokyo University. In comparison to the neoclassical growth theory (Solow, 1956), the endogenous growth theory focused primarily on the explanation of the three factors that influence economic growth: technology, labour, and capital. Until that time, growth had been considered exogenous and its causes had not been explained. Lucas and Romer, instead, concentrated on the growth of technology and on how it depends on – i.e. is endogenous to – investments in the field of research, education, and state intervention by means of incentives. This theory has greatly influenced governmental economic policies in a number of industrialised countries, since improvements made to the education system, as well as incentives to firms for research and development activities (Gibbons & Johnston, 1974), are decisive elements for the increase in productivity both of firms and of national innovation systems. These interventions reflect the endogenous growth theory.

4. Concluding observations

During its development, economics gave rise to a series of specialised lines of study, among which that of the economics of scientific research, which must be based on the study method of the science that originated it. According to Pareto (1911), the study of economics has the following main purposes: 1) collecting guidelines that will be useful to private individuals and to the public authorities in their economic and social activities; 2) solely aiming at investigating phenomena and their laws. The intention is, in this case, exclusively scientific.

In order to become an autonomous discipline, the economics of scientific research must focus, above all, on the second matter highlighted by Pareto: investigating the laws of the origin of scientific research, of scientific production, of management and organisational behaviour of scientific institutions, leaving issues concerning innovation to other disciplines. It is clear that, by generating inventions and innovations, the process of scientific research creates natural interferences between the two fields of investigation, but they should be kept separate, because research is a phenomenon preceding those of invention and innovation. The economics of scientific research is a branch of economics that investigates the subjects (scientists and institutions) involved in the process of scientific production, in order to provide the means to meet people's and society's needs. Rosenberg's (1974) stress on the problem-solving nature of scientific knowledge, which is echoed by Hicks (1995). If the process of scientific research reaches its goal, it affords the attaining of a greater amount of products with the same costs or the same amount of products with lesser costs, as well as goods for consumption that instruct and entertain the public in general.

The economics of scientific research has made fundamental theoretical and empirical advances in the 1990s. In particular the work of Mansfield (1991, 1995), Narin *et al.,* (1997), Narin & Olivastro (1998), Crow & Bozeman (1998), Hicks & Katz (1997) have shone new light on the economics of scientific research. Scientific research has recently become more and more relevant and is the subject of numerous studies, but it is difficult to investigate because based on a market imperfection due to the absence of prices. Moreover, research is becoming more international, more interdisciplinary, more directed towards application and conducted more by groups and networks of researchers (Gibbons *et al.,* 1994). The objectives of scientific institutions are far more complex than those of firms: universities and public research bodies should maximise prestige, which in turn is a function of other variables that are not easily measured. Several research institutes are public and financed by the government, whose objective is maximising the value added for society. The most difficult matter, when analysing scientific research, is its multidimensional nature, which often leads scholars to use methodological tools borrowed from other disciplines, such as sociology, psychology, industrial organization, and so on. Despite the difficulties scholars have to face when analysing scientific issues, it is hoped that in the future the economics of research shall gain a clearer identity, capable of endorsing its development as an autonomous branch of economics. Its interdisciplinary foundation should be seen as one of its strengths, capable of making the discipline more fertile and allowing for further advancements.

Notes

[i]Seestudies by Calabrese *et al.,* 2005; Cariola & Coccia, 2004; Cavallo *et al.,* 2014, 2014a, 2015; Coccia, 2001, 2003, 2004, 2005, 2005a, 2005b, 2005c, 2006, 2006a, 2007, 2008, 2008a, 2008b, 2009, 2009a, 2010, 2010a, 2010b, 2010c, 2010d, 2010e, 2011, 2012, 2012a, 2012b, 2012c, 2012d, 2013, 2013a, 2014, 2014a, 2014b, 2014c, 2014d, 2014e, 2014f, 2014g, 2015, 2015a, 2015b, 2015c, 2015d, 2016, 2016a, 2016b, 2016c, 2017, 2017a, 2017b, 2017c, 2017d, 2018, Coccia & Bozeman, 2016; Coccia & Finardi, 2012, 2013; Coccia & Wang, 2015, 2016; Coccia & Cadario, 2014; Coccia *et al.,* 2015, 2012, Coccia & Rolfo, 2000, 2002, 2009, 2012, 2007, 2010, 2010, 2013; Coccia & Wang, 2015, 2016; Rolfo & Coccia, 2005.

[ii] Bacon isknownas the father of the English empiricistphylosophy, a traditionthatincludes Locke, Hume, J.S.Mill, Russel.

[iii]Alessandro Volta (1745-1827) Italianphysicist, known for hispioneering work in electricity, invented the ElectricBattery in 1800.

[iv] The origins of the scientificmethod date back to Aristotele (384 B.C.-322 B.C.), whowasone of the first to describe the deductiveprocess, while Bacon (1561-1626) was the first scientist to developaboveall the inductivereasoning, that Galileo (1564-1642) latercompleted by addinghismathematicformalisation.

[v]Lazzaro Spallanzani. (Italy, 1729-1799) is one of the great names in experimental physiology and the natural sciences. His investigations have exerted a lasting influence on the medical sciences. He made important contributions to the experimental study of bodily functions and animal reproduction. His investigations into the development of microscopic life in nutrient culture solutions paved the way for the research of Louis Pasteur.

[vi] Vannevar Bush director of the Office of ScientificResearch and Development whichwasalsoresponsible of the Manhattan Project.

[vii]Bernalwas the first to perform a measurement of science in a Western country. In *The Social Function of Science* (1939), Bernalestimatedthe moneydevoted to science in the United Kingdom (UK) usingexistingsources of data: governmentbudgets, industrial data (from the Association of ScientificWorkers) and UniversityGrantsCommittee reports. He wasalso the first to suggest a type of measurementthatbecame the mainindicator of science and technology: Gross Expenditureson Research and Development (GERD) as a percentage of GrossDomestic Product (GDP). He compared the UK's performance with that of the UnitedStates and USSR (nowFederation of Russian States) and suggestedthat Britain should devote betweenonehalf and onepercent of itsnationalincome to research.

[viii] The Matthew effect in science isnamed for the verse in the Gospel according to St. Matthew: *for unto everyonethathathshall be given, and he shallhaveabundance: but from himthathathnotshall be takenawayeventhatwhich he hath* (Matthew, XXV, 29).

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