Economic and social studies of scientific research Nature and origins

Mario Coccia

(Ceris-Cnr, Italia e Max-Planck Institute of Economics, Germania)

National Research Council of Italy, Ceris-Cnr
Via Real Collegio, 30
10024 Moncalieri (To) – Italy
Tel.: +39.011.6824.925; Fax: +39.011.6824.966; email: m.coccia@ceris.cnr.it

ABSTRACT. Interest in the role that science and scientific research play in economics and the other social sciences has exploded in the last fifty years. This attention undoubtedly reflects the increased importance that scientific research is contributing more and more to employment and economic growth, as well as the comparative advantage of countries. The purpose of this paper is to investigate the nature and origins of the studies which focus scientific research and organization (such as economics of science, sociology of science, managerial economics of research organizations, political economy of science, etc.). The paper shows as the foundations of this discipline are the works of Huxley, Bernal, Bush, Peirce, Polanyi, and Freedman and the success of the Manhattan and Rand projects (1930s-1950s) that symbolised the power of big science projects involving governments, scientists, industrialists and universities.

KEYWORDS: Science, Scientific research, Sociology of science, Social studies of science, History of science, Research policy, Research laboratory, Research management

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Direttore Responsabile
Secondo Rolfo

Direzione e Redazione
Ceris-Cnr
Istituto di Ricerca sull'Impresa e lo Sviluppo
Via Real Collegio, 30
10024 Moncalieri (Torino), Italy
Tel. +39 011 6824.911
Fax +39 011 6824.966
segreteria@ceris.cnr.it
http://www.ceris.cnr.it

Sede di Roma
Via dei Taurini, 19
00185 Roma, Italy
Tel. 06 49937810
Fax 06 49937884

Sede di Milano
Via Bassini, 15
20121 Milano, Italy
tel. 02 23699501
Fax 02 23699530

Segreteria di redazione
Maria Zittino e Silvana Zelli
m.zittino@ceris.cnr.it

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Multa sunt quae esse concedimus; qualia sunt? Ignoramus. Habere nos animum, cuius imperio et impellimur et revocamur, omnes fatebuntur; quid tamen sit animus ille rector dominusque nostri, non magis tibi quisquam expediet quam ubi sit. Alius illum dicet spiritum esse, alius concentum quendam, alius vim divinam et dei partem, alius tenuissimum animae, alius incorporalem potentiam; non deerit qui sanguinem dicat, qui calorem. Adeo animo non potest liquere de ceteris rebus ut adhuc ipse se quaerat. Quid ergo miramur cometas, tam rarum mundi spectaculum, nondum teneri legibus certis nec initia illorum finesque notescere, quorum ex ingentibus intervallis recursus est? Nondum sunt anni mille quingenti ex quo Graecia stellis numeros et nomina fecit, multaeque hodie sunt gentes quae facie tantum noverunt caelum, quae nondum sciunt cur luna deficiat, quare obumbretur. Haec apud nos quoque nuper ratio ad certum perduxit. Veniet tempus quo ista quae nunc latent in lucem dies extrahat et longioris aevi diligentia. Ad inquisitionem tantorum aetas una non sufficit, ut tota caelo vacet; quid quod tam paucos annos inter studia ac vitia non aequa portione dividimus? Itaque per successiones ista longas explicabuntur. Veniet tempus quo posteri nostri tam aperta nos rescisse mirentur.

Seneca Naturales Quaestiones (VII, 25, 1-5)[1]

[1] The slow path of knowledge
«Many are the things of which we admit the existence. But of which nature they are, we do not know. Anyone would admit that they are endowed with spirit, whose commands at times stimulate us, at times refrain us from acting, but what that spirit is, our supreme guide, is a problem that no one would be able to explain to you, as well as where it dwells. One shall say it is the vital force; the other shall say it is a sort of harmony; yet another that it is divine energy and part of divinity; another shall say it is the purest part of the breath of life; another that it is an incorporeal power; and there shall be also those who identify it with blood or heat. At this stage, our spirit can not have certainties about other things, since it is still looking for itself. So then why do we wonder why comets, such a rare cosmic display, have not yet been explained on the basis of precise law and why we do not yet know the beginning and the end of those phenomena that recur at remarkably long intervals? It is not yet one thousand five hundred years since Greece "numbered and named them" and today there still are many peoples who know the sky only in its visible part and who do not yet know why the moon is eclipsed, why it darkens. These phenomena have also been explained among us only in recent times. A day shall come when what now escapes shall be brought to light by time and by the research of several generations. In order to investigate such big phenomena one single life is not enough, even admitted that one dedicates it entirely to the study of the sky; what shall we say then about the fact that these few years of ours are divided, not equally, between intellectual activities and our weaknesses? Therefore, those phenomena shall be explained in the long flow of years. A day shall come when our descendants will be surprised at the fact that we ignored such plain things». Seneca Naturales Quaestiones (VII, 25, 1-5).

INTRODUCTION

Interest in the role that science and scientific research play in economics and the other social sciences has exploded in the last fifty years. In fact the scholars have generated a wave of studies and inquiry focusing on science and scientific research. This attention undoubtedly reflects the increased importance that science and scientific research have for economic growth (Romer, 1994), as well as for the comparative advantage of countries (Porter, 1988). This literature has the special characteristic of spanning a number of fields such as economics, sociology, managerial economics, political economy, economic history, philosophy, and so on. For instance, the basis of economics of science solidified when the Journal of Economic Literature invited Paula Stephan to summarize what is known and not known about the economic analysis of science. 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 the appropriability problem associated with the production of a public good.*

Despite the remarkable efforts made in the twentieth century (Martin and Nightingale, 2000; Stephan and Audretsch, 2000; Garonna and Iammarino, 2000), there is confusion in the economic literature both about the terms 'science' and 'research', commonly used as if they were synonyms even though the two concepts are actually different, and the origins of the social studies of science.

In view of such issues, the purpose of this article is to answer the following questions: what is the nature of scientific research? What is the difference between science and scientific research? What is the origin of studies on social dimension of science and scientific research organizations? Who are the first scholars that have analysed problems concerning science and scientific research organizations? The answers to these questions can clarify the nature and origins of the science analysis that play a more and more fundamental role in the knowledge era. The following section of this paper analyses the nature of the science and scientific research, while the third section analyses the origins of the economics and social studies on science and scientific research. The last section of the paper focuses on some concluding remarks.

1. NATURE OF SCIENTIFIC RESEARCH

The scientific research is a type of research associated to science. 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).*

Since scientific research derives directly from science, 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).*

William 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.*

Bertrand 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.*

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) 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. Volta argues that 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 defines normal science as 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. According to Paul Freedman (1960) the definition of 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 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, which is infinite. 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 couture art), include not only all the pure but also all the applied branches of science. An adequate definition of science must include all genuine science even in its very early stages, however elementary. 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 may be 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 words the definition of science, I 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 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 the other 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).

The prodigious development of many sciences is pushed by the application of two scientific methods *inductive* and *deductive*[2]. 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 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, more precisely among those scientists interested in the social aspects of science. Bernal (1939) used the terms "pure" and "fundamental" interchangeably.

In June 1963, Organisation for Economic Co-operation and Development (OECD) experts met at Frascati (Italy) and the results of their work is a document, called Frascati manual (OECD, 1968) which also 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).

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[2] The origins of the scientific method date back to Aristotele (384 B.C.-322 B.C.), who was one of the first to describe the deductive process.

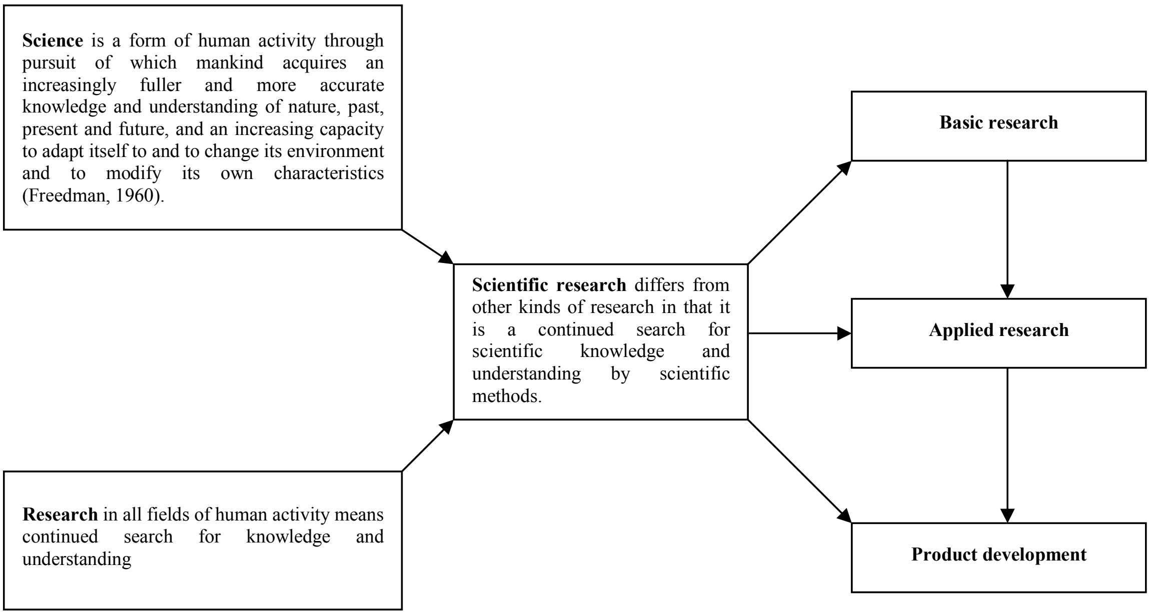


Figure 1: Derivation of scientific research and its taxonomies

Joseph Needham (1959) reported that 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".

2. ORIGINS OF THE ECONOMIC AND SOCIAL ANALYSES OF SCIENCE AND SCIENTIFIC RESEARCH ORGANIZATION

Although there have been several contributions to the social studies of science in the last few years, the origins of these disciplines can be traced back to philosophers and 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 (1561-1626)[3], who believed that science had the power to improve the society's economy and standard of living. In his work *New Atlantis* (Weinberger, 1976), he saw science, technology, politics, industry, and religion as deeply intertwined. Bacon is also important because he was one of the first to suggest a link between organisation of science and economic progress.

Bacon Francis (1561-1626)

Bacon's work marked the beginning of a new way of thinking about the science. Bacon was also the first scientist to develop the inductive reasoning, that Galileo (1564-1642) later com-

[3] Bacon is known as the father of the English empiricist phylosophy, a tradition that includes Locke, Hume, J.S. Mill, Russel.

pleted by adding his mathematic formalisation. Scientific and technical advances have always been important to military success, from the Roman empire, to information, telecommunications and electronics in the Iraq war.

Galileo Galilei (1564-1642)

The foundations of the economics and analysis of science and scientific research are the studies carried out by Lotka (1926) with the paper *The frequency distribution of scientific research,* Huxley (1934) with the book *Scientific research and social needs,* Bernal (1939) *The social function of science,* Bush (1945) *Science: the endless frontier,* Peirce (Klosel, 1986) with several contributions, Freedman in 1949 with the 1st edition of his book *The principles of scientific research* (Freedman, 1960), and Polanyi with is book *Personal Knowledge* (1962).

Alfred Lotka (Ukraine, 1880 – 1949 USA), chemist, demographer, ecologist and mathematician, was born in Lviv (Lemberg), at that time situated in Austria, now in Ukraine. He came to the United States in 1902 and wrote a number of theoretical articles on chemical oscillations during the early decades of the twentieth century, and authored a book on theoretical biology (1925). He is best known for the predator-prey model he proposed, at the same time but independent from Volterra (the Lotka-Volterra model is still the basis of many models used in the analysis of population dynamics).

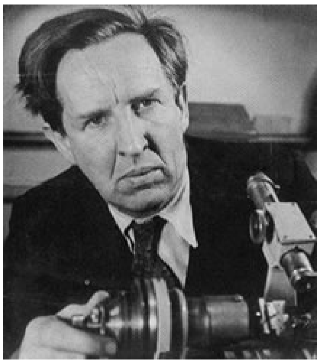
Alfred Lotka (1880–1949)

The article that made him famous as a bibliometrician is just a footnote in his oeuvre (Lotka, 1926). He showed that the number of authors with n publications in a bibliography is described by a power law of the form C/n^a, where C is a constant. The exponent a is often close to 2. Rewriting this equation as a statistical distribution (so that the sum over all n becomes 1), he showed that in the case that a is exactly equal to two, C must be $6/(pi)^2$, or approximately 0.61. This means that if a bibliography can be described by Lotka's square law, approximately 61% of all authors have contributed just one article to this bibliography.

Sir Julian Sorell Huxley (UK, 1887-1975) was a British biologist, known for his popularizations of science in books and lectures. Huxley was part of a distinguished family (the father, Leonard was writer, the grandfather, Thomas H. was biologist). Huxley, 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. Basic research defined by Julian S. Huxley, was later appropriated by Vannevar Bush (1945). Moreover for Huxley (1934), ad hoc meant applied research, and development meant more or less what we still mean by it today. Huxley (1934) writes his book, visiting research laboratories and university departments of all kinds, from those concerned with the purest of science to those involved in direct production. He analysed the innumerable channels through which the fund of knowledge pours out into its multitude of social applications. The book of Huxley is one of the first surveys of science in relation to many aspects of social needs. According to Huxley the nations are not isolated so completely from one another that each can be dealt with on its own. He highlights the interactive nature of science and society.

Thomas (grandfather) and Julian Huxley (1887-1975)

John Desmond Bernal (1901, Ire; 1971, London, UK) was a prominent international scientist, born in Nenagh, Co Tipperary, Ireland. He did pioneering work in X-ray crystallography. He was Professor of Physics at Birkbeck College, University of London and a Fellow of the Royal Society. He ranged widely in his intellectual interests and activities, also doing pioneering work in social studies of science or "science of science". Bernal was the first to perform a measurement of science in a Western country. In *The Social Function of Science* (1939), Bernal estimated the money devoted to science in the United Kingdom (UK) using existing sources of data: government budgets, industrial data (from the Association of Scientific Workers) and University Grants Committee reports.



John Desmond Bernal (1901-1971)

He was also the first to suggest a type of measurement that became the main indicator of science and technology: Gross Expenditures on Research and Development (GERD) as a percentage of Gross Domestic Product (GDP). He compared the UK's performance with that of the United States and USSR (now Confederation of 11 former Soviet republic such as: Russia, Ukraine, Armenia, and so on) and suggested that Britain should devote between one half and one percent of its national income to research. Moreover Bernal (1939) was another adherent of the view that science had the potential to be an 'engine of progress' but he writes between the two World Wars and was not optimistic about science. Bernal's work explicitly recognises the lack of direct link between science and scientific progress. Bernal argues that science should be centrally planned and controlled by the state. Bernal's view was contested by Polanyi who, like Vannevar Bush, saw science as a separate field that should not be interfered with by government officials who do not understand the complex technical details required to manage science (Polanyi, 1962). Barnal believes that most fruitful advances, during the next epoch of scientific inquiry, must come from researches in biology, psychology, and social sciences. Moreover he believes that when writes the book, they are witnessing the third stage in social evolution of mankind. The first was the rise of society and the transmission of experience. The second was the rise of civilization based on agriculture. The third is to be the suppression of traditional techniques by science. Bernal reports that a comprehensive plan for rationalising the supply and distribution of scientific information, and the proposal that universities should invest in their own instruments plants, instead of wasting money on buying their apparatus at retail prices (Wootton, 1939).

Vannevar Bush (1890-1974)

Vannevar Bush (USA, 1890-1974) was an American engineer known for his political role in the development of the atomic bomb, and idea of memex - a pioneering concept for the World Wide Web. Vannevar Bush was director of the Office of Scientific Research and Development and also responsible of the Manhattan Project. Bush's *Science: The endless frontier* was very influential in advocating a science push model to the American science policy community. According to this model the investments in science produce technology, which in turn generates economic growth. It argued for a "hands off" approach to science policy and suggested that science would generate economic growth and improved quality of life if it was simply publicity funded and left to organise itself.

Charles Sanders Peirce (USA, 1839-1914) was the founder of American pragmatism. In the course of his polymathic researches, he wrote on a wide range of topics, ranging from mathematical logic to psychology. His understanding of the scientific method is not far different from the standard idea of the scientific method as being the method of constructing hypotheses, deriving consequences from these hypotheses, and then experimentally testing these hypotheses. Peirce described the scientific method as consisting of abduction, deduction, and induction, plus the economics of research (Kloesel, 1986). Abduction is inference to some explanation. Deduction is the drawing of conclusions as to what observable phenomena should be expected if the hypothesis is correct. Induction is the entire process of experimentation performed in service of hypothesis testing. Peirce's idea of the economy (or: the economics) of research is an ineliminable part of his idea of the scientific method (Coast survey report, 1876). He understood that science always operates in some given historical and socio-economic context, in which some experiments may be crucial and others insignificant.

Charles Sanders Peirce (1839-1914)

He understood that the economic resources of the scientist are severely limited, while the "great ocean of truth" that lies undiscovered before us is infinite. Research resources, such as personnel, time, and apparatus, are costly; and it is irrational to squander them. He proposed, therefore, that careful consideration be paid to the problem of how to obtain the biggest epistemological "bang for the buck." In effect, the economics of research is akin to a cost/benefit analysis in connection with states of knowledge. Peirce regarded it as central to the scientific method and to the idea of rational behaviour.

Michael Polanyi (1891-1976)

Michael Polanyi (1891-1976), born in Budapest (Hungary), where he studied at the University gaining doctoral degrees both in medicine and physical science and afterwards at Karlsruhe (Germany). Polanyi did a lot of contributions to the literature of social science and philosophy, and became Professor of Social Sciences at Manchester (1948-58). Central to Michael Polanyi's thinking was the belief that creative acts (especially acts of discovery) are shot-through or charged with strong personal feelings and commitments. In respect of the philosophy of science, it can be argued that Michael Polanyi helped to pave the way for Thomas Kuhn's groundbreaking work on the structure of scientific revolutions. From the mid-1930's, Polanyi began to articulate his opposition to the prevailing positivist account of science, arguing that it failed to recognise the part played by tacit knowledge (Polanyi, 1966). He viewed positivism as encouraging some to believe that scientific research ought to be directed by the State. Polanyi, like Hayek, believed that a free market facilitates the use of tacit knowledge within a society. This helps society to self organize, facilitating the pursuit of various goals.

Paul Freedman was a British electrical engineer who apparently spent most of his research career in industrial laboratories. He stresses throughout that ability to do first-class research is not shared equally by all scientists. His purpose in writing is largely -to encourage young scientists who may have the gift not to give up science before they find opportunities to develop and use their gift. Freedman sorts out real innovators in science from mere accumulators of knowledge. The content main of his book (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 based on 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) where he argues a choice between accuracy and economy, and determining the minimum number of essential observations. He also estimates the amount of time necessary to "finalize" a piece of research before going on to something else. Part III is focused on the support available for research.

Important is the chapter VII on the *Organization* and the XI *Patrons*. Freedman states that in the early stage of its history scientific research was invariably individual research. Later larger organizations developed. In the twentieth large organizations appeared in which research was carried out by teams of scientists working in collaboration. He states that research team work was originated not by scientists but by their patrons (Governments, headquarters, foundations, etc.). He states four main types of teams, and the best type of team is characterised by the head of research, who may be a first-class scientist, and is at any rate a scientist of repute. The organization is composed of a number of autonomous team units, each concerned and capable of carrying out a complete piece of research. According to Freedman the head of any research organization must possess, besides his scientific ability, a number of qualities fitting him for leadership of those his direction. Moreover he states that all research organizations have a scheme of work that involves a choice between rigid and elastic plans of work, and between working to a time schedule or ignoring the time elements. The question of working to a rigid or elastic plan, to a rigid or elastic time schedule, leads to the question of discipline. Discipline in a research organization may be imposed, or may be self-discipline, or a combination on the two. A men engaged on research is at his best when he feels completely free and "at home" in the laboratory. Consequently restrictions which operate normally in mass production establishments should be waived in a research organization.

The Freedman's book is written subsequently to the Second World War, when researches began to be carried out mainly in research laboratories. In fact the scientists involved in the Manhattan project established one of the first research laboratories. The United States initiated this project under the Army Corps of Engineers in June 1942. 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, such as 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 staff members with expertise in a wide range of fields including: mathematicians, engineers, economists, chemists, physics, aerodynamicists, and so on. For Bush, the success of these projects 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 laboratories, 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. In all, de Solla Price (1965)[4] recognises the interaction between science and technology and uses the metaphor of two dancing partners who are independent but move together. These studies together with specific historical circumstances related to the World Wars led to the origin and development of the economics and social analyses of scientific research and scientific organization which involve disciplines such as: Economics of science, managerial economics of research organizations, sociology of science, political economy (science and research policy), history of science, philosophy of science, etc. For instance, Richard Nelson (1959) with the article *The Simple Economics of Basic Scientific Research*, traces some foundations of the economic analyses concerning science that provide the basis of our modem understanding (see also, Pavitt, 1993; Pavitt, 2001; Salter and Martin, 2001).

[4] Derek de Solla Price was born in Leyton, near London (UK) and obtained a Ph.D. in experimental physics from the University of London in 1946. After a three-year teaching assignment at Raffles College (Singapore), he returned to England and obtained a second doctorate, now in the history of science. He successively worked at Princeton and the Smithsonian Institute. At Yale, where he remained until his death, he was appointed Avalon professor of history of science. He studied the exponential growth of science and the half-life of scientific literature. In a famous article "Networks for scientific papers' he drew attention to the interactive communication patterns of scientists, as shown by citations to each other's work. His article on cumulative advantage processes, interpreting Herbert Simon's theory, earned him the best JASIS paper award (1976). He is a pioneer and outstanding figure of the sociology of science and has been called 'the father of scientometrics'. In 1984 he received, posthumously, the ASIS Research Award for outstanding contributions in the field of information science.

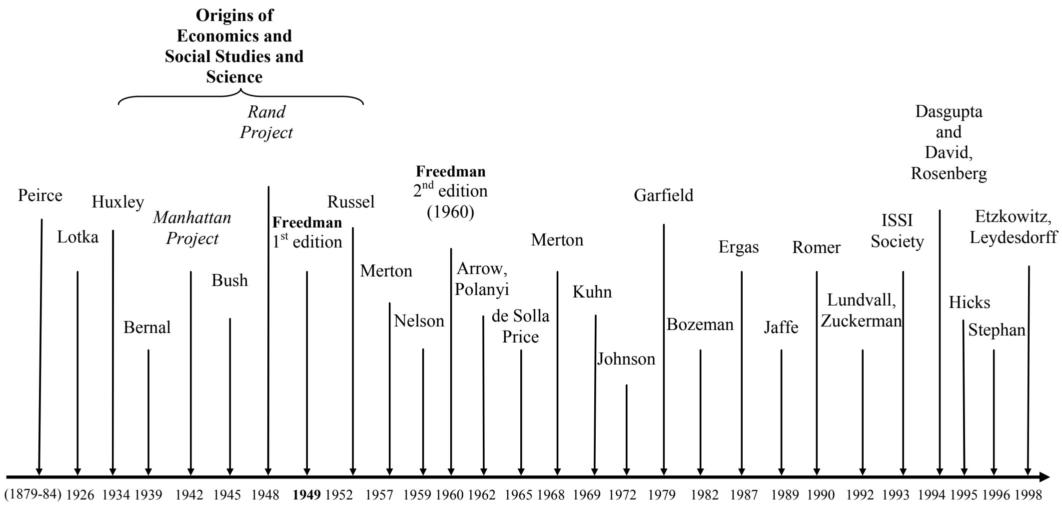


Figure 2: Origins and main contributions to the social studies of scientific research

After the pioneering contributes of Lotka, Huxley, Bernal, Peirce, etc. (1900s-1950s), contributions to the social aspects of scientific research and research organizations became more and more numerous, so much so that today there are several journals that deal with these issues, among them, some of the most prominent are: "Minerva: A review of science, learning, and policy" (established in 1962); "Social Studies of Science: An international review of research in the social dimensions of science and technology" established in 1970; "Prometheus"; "Research policy", and others that deal with more specific topics.

Figure 2 places the origins of the main social study concerning the scientific research and research organizations when the World Wars led to the institution of the organised laboratories for the production of scientific research necessary for military purpose. Figure 2 also displays, in chronological order, the main contributions that have developed the social studies of science and scientific organizations.

3. CONCLUDING REMARKS

The wide range of scholarly disciplines involved in research on the social analysis of science has made it difficult for scholars in any one field to grasp the research contributions and to offer courses, at universities on the social dimension of science.

These studies have to investigate the laws concerning the scientific research production, management, researchers and organisational behaviours, relationships between research and society, and so on. Moreover, the process of scientific research, by generating inventions and innovations, has natural interferences with the economics of innovation, but these disciplines should be kept separate, because scientific research is a phenomenon preceding those of invention and innovation, and it has different implication for organization, society, scholar, economy, etc. The social analysis of science investigates the subjects (scientists and institutions) involved in the process of scientific production, in order to analyse as scientific research satisfies the people's and society's needs. The social studies of science should also investigate as to increase the scientific production (new knowledge, technological and social innovation, as well as goods that instruct and entertain the public in general) and the well being for the society with the same costs or to produce the same amount of research with lesser costs. Rosenberg's (1974) stress on the problem-solving nature of scientific knowledge which is echoed by Hicks (1995).

The social studies of scientific research have made fundamental theoretical and empirical advances in the 1990s. In particular the work of Mansfield (1991, 1995), Narin *et al.* (1997), Narin and Olivastro (1988, 1998), Crow and Bozeman (1998), Hicks and Katz (1997) have shone new light on this subject. Scientific research has recently become more and more relevant, but it is difficult to investigate it. 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 source of scientific research is the scientific institution which is more complex than firm: universities and public research bodies maximise prestige, which in turn is a function of other variables that are not easily measured. 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, management, economics, and so on. Any way the interdisciplinary foundation of science should be seen as one of its strengths, capable to generate cross-fertilization and allowing for further advancements of the discipline.

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CERIS-CNR, Via Real Collegio, 30; 10024 Moncalieri (Torino), Italy
Tel. +39 011 6824.914; Fax +39 011 6824.966; m.zittino@ceris.cnr.it; http://www.ceris.cnr.it