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# Periodization Problems in the Economic History of Science and Technology

## Problemas de Periodización en la Historia Económica de la Ciencia y la Tecnología

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**ABSTRACT**

Nowadays there is no doubt about the interrelation between and mutual dependence of scientific and technical progress on the one hand and economic development on the other. Since this has not always been so, it has become necessary to define and to justify the time from which we may conceive an economic history of science and technology. This problem is easier to solve in relation to the latter than with regard to the former: the relationships between the scientific and the economic systems of any society are not only much more recent than those of the economy with its underlying techniques, but they are also predominantly indirect, usually mediated by or linked to some form of technological development. Technology acquired a scientific basis with the Second Industrial Revolution, whose nature however can only be understood when contrasted with that of the First one as well as with the processes of the professionalization of research and of the transition from natural philosophy and natural history to the contemporary scientific disciplines, both of which took place from the mid-eighteenth century onwards.

*KEY WORDS: Economic History, Science, Technology, Economic Development*

*JEL Codes: N73, 030, 039, 123*

**RESUMEN**

Actualmente no hay dudas sobre las interrelaciones y la mutua dependencia entre el progreso científico y técnico de un lado y el desarrollo económico del otro. Como esto no siempre fue así, se torna necesario definir y justificar las épocas a partir de las cuales podemos concebir una historia económica de la ciencia y la tecnología. Este problema se resuelve más fácilmente con respecto a la segunda que en relación a la primera: los nexos entre los sistemas científico y económico de cualquier sociedad no sólo son mucho más recientes que los de la economía con sus técnicas subyacentes, sino que también suelen ser predominantemente indirectos, usualmente mediados o vinculados a algún tipo de desarrollo tecnológico. La tecnología adquirió una base científica con la Segunda Revolución Industrial, cuya naturaleza todavía solamente puede ser entendida en confrontación con la de la Primera, así como con los procesos de profesionalización de la investigación y de transición de la filosofía y la historia natural hacia las disciplinas científicas contemporáneas, procesos ambos que fueron ocurriendo desde mediados del siglo XVIII.

*PALABRAS CLAVE: Historia Económica, Ciencia, Tecnología, Desarrollo Económico*

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* Tamás Szmrecsányi falleció el pasado 16 de febrero mientras el presente artículo estaba siendo evaluado por *IHE*. Se publica simultáneamente este artículo en la *Revista Brasileira de História da Ciência*, volumen 2, número 1, páginas 6-22, como homenaje a uno de los investigadores claves de la Historia Económica. El proceso de evaluación ha sido realizado por *IHE*.

## 1. Introduction[1]

Within the human and the social sciences, any academic work results in the linking of some spatial contexts to one or more individual epochs. These are the boundaries in time and space which limit the reach of its research as well as the validity of the generalizations it may aspire to. In the specific field of historical studies, these limits are in great part set by the period of analysis. Periodization assumes a particular importance in relation to them because of its connection with the very definition of their subjects —namely the *changes* of structures, conjunctures, and institutions (economic, political, social or cultural) *through time*. These changes involve not only the various social economic agents and their respective activities, but also the different results and processes originating from them.

Such characteristics obviously also apply in full to the economic historiography of science and technology (both of them understood as specific sets of human knowledge), which, together with the historical study of the policies that determine their formulation and reformulation over time, refer on the one hand to the evolution of the relationships between them, and on the other hand to those of both with the social and economic conjunctures, structures and institutions. The historiography (still to be constructed)[2] involves in consequence the relationship between two levels of social production and reproduction: the production and reproduction of science and technology at the theoretical level, and the production and reproduction of economic systems (micro and macro) at the practical level, thus involving not only the supply of all kinds of goods and services, but also the activities of the agents and organizations producing and distributing them, all of which are constantly interacting with each other.

From the viewpoint of conventional science and technology historiographies this economic historical study constitutes essentially an *externalist* approach, due to the priority that it gives and the constant reference it makes to the environment in which the scientific and technological activities and knowledge evolve. In practice, however, this orientation neither exhausts the procedures of that study nor does it frontally oppose the so-called *internalist* approaches of those historiographies which traditionally limit their analyses to the intellectual and technical aspects of the evolution of science and technology[3]. To be sure, these analyses are not only valid and relevant in themselves, but they are also useful for the identification and incorpora-

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1 An initial version of this paper was presented in Portuguese at the First Latin American Economic History Congress, held in December 2007 in the city of Montevideo.

2 With respect to this, see my former articles Szmrecsányi (2000 and 2003).

3 Good discussions on these concepts can be found in Porter (1991), especially pp. 35-36 and 39-41; and in Fuller (2000).

tion of the non-economic or extra-economic determinants and specifics of scientific and technological research, which cannot and should not be reduced to simple knowledge generating mechanisms for the production of goods and services.

At the same time however it has to be admitted that these specific and specialized analyses, by usually being limited to the theoretical and methodological domains of science and technology, only seldom manage to fully capture and characterize the origins, the development and the effects of both. Therefore, without rejecting or leaving aside the *internalist* visions, but only seeking to transcend and complement them, the economic historiography of science and technology is capable of providing an important contribution towards clarifying these issues, be it by incorporating contextual variables into the analysis of scientific and technological knowledge's evolution, be it by linking this evolution to the assessment of changes occurring in other spheres of economic and social life, and also —or perhaps mainly—by seeking to reinsert the evolution of that knowledge within the totality of historical development.

In other words, and attempting to synthesize what has been stated up to this point, the economic historiography of science and technology purports not to lose sight of the interactions which mutually relate to the progress of science, that of technology, and economic progress (or, rather, economic development). The question of how to achieve this was duly posed forty years ago in a brief but important paper presented by Bertrand Gille to the Fourth International Congress of Economic History[4]. Nonetheless, that paper left open the question of the times whence we may put into practice its recommended procedures —namely the period and the circumstances from which it becomes possible to conceive and formulate an economic history of science and technology, if not for any country or the world as a whole, at least in relation to the richest and most developed economies of the present, usually bearers of ample data bases and already subjected to comprehensive and rigorous historical studies.

This problem seems easier to solve with regard to technology than in relation to science, taking into account the fact that techniques have always been a part of productive processes, thus giving rise to more or less direct relationships between technical progress (conditioned by technological development) and economic progress (or development), both at macro and micro levels. Due to this, by exclusively considering an economic history of technology, we may begin to study it at the time and place of our preference without having to seek wider explanations and justifications for our eventual choice. But, when it comes to the relationship between science and economic development, we are immediately faced with the fact that this relationship

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4 Gille (1975).

in addition to being historically more recent, is only rarely direct, and usually tends to be mediated by technology, thus introducing the additional problem of having to study the latter's links to particular scientific disciplines.

## 2. Science, Technology And Economic Development

We know in hindsight that technology only came to acquire a more scientific character with and through the Second Industrial Revolution, whose development in "the present-day richest and most advanced economies extended from the mid-nineteenth century to the early 1930s (a fact that enables us to situate the beginning of the Third one, still in flux, at the time of the Second World War, which gave rise to several contemporary technologies). However, the productive reconstruction determined by the Second Industrial Revolution only becomes fully intelligible in the context of its causes, the unfolding and the ramifications of the First Industrial Revolution which had preceded it, starting in Britain in the mid-eighteenth century and being completed in the most developed economies of our time during the first decades of the following one. Due to reasons presented in the previous paragraph, there is no reason not to put back to that period, or even before, the beginnings of any study about the relationships between technical progresses and the development of those economies. The problem which arises refers to whether we may do the same when studying the relationships between the progress of the sciences and technological development, and of both *vis-à-vis* the period's economic development.

The discussion of this problem has given rise, up to now, to two kinds of conflicting and contradictory arguments: an older and more familiar one, of those who either defend or deny the existence of direct relationships between the First Industrial Revolution and the Scientific Revolution which occurred in the sixteenth and the seventeenth centuries; and another, more recent and less well-known, related to dating the origins and initial evolution of modern science —i.e. of the scientific disciplines presently cultivated and developed throughout the world. Leaving aside the former of these, whose terms have already been consolidated in a large and diversified bibliography, we may concentrate our attention on the latter, due to its more direct relation to our periodization problem[5]. This problem involves not only the explicitness but also a justification of the criteria adopted in the choice of the period to be studied.

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[5] We can mention, on the one hand, the positions defended by books like those of Musson & Robinson (1969) and Jacob (1997), and on the other, the criticism of them by articles such as those of Hall (1974) O'Brien (1991) and Wengenroth (2003).

My own preference for this alternative approach has been partly motivated by the polemical and instigating character of two articles by Andrew Cunningham, pointing to the specialization and eminently contemporary nature of the scientific disciplines of our time. These disciplines, according to him, are not only very distant from those practiced until the mid-eighteenth century, but can neither be automatically nor directly linked to them.

The first of these articles was published twenty years ago and called the readers' attention to the fact that, in previous epochs of a more distant past, scientific knowledge did not have the same functions, meaning and relevance as nowadays, frequently intertwining with philosophical and even religious reflections and propositions[6]. Viewing the production and reproduction of such knowledge as a conscious and deliberate human activity practiced by specific people, Cunningham stressed that our present concepts of science and scientists plainly did not exist in those former times, thus making any application of the present day historiography of scientific disciplines hazardous and arbitrary. The historical reconstruction of the events, phenomena and processes of any epoch has to take into account the reality existing in it, and not our actual conception of the same events, phenomena or processes. Within this perspective the scientific disciplines of the present day cannot simply be equated to bygone times' natural history, natural philosophy, or philosophy *tout court*. We have to respect the historical meaning of both the titles and the contents of Boyle's or Newton's works, as well as the historical signification of the Royal Society of London, whose periodical, not by chance, had the title of *Philosophical Transactions*.

In those times the term "science" already existed both in English and in French (originating from the Latin word *scientia*), but had a meaning similar to that of the Greek word *episteme*, which refers to knowledge in general and not as nowadays to a specific mode of knowledge (i.e. scientific knowledge). Until the end of the eighteenth century it was common to include among the sciences such disciplines as logic, grammar, ethics and theology[7]. For this reason there can be no doubts regarding the evolution that has taken place from the natural philosophy of the eighteenth century and before up to our present day scientific disciplines, an evolution which has been both quantitative and qualitative, and whose main aspects and effects are easily perceptible. The only question which remains open is that of defining when, why and how the transition occurred from one reality to the other. At the end of his article, Cunningham situated the "invention" of the modern sciences at a period between

6 Cunningham (1988).

7 On the semantic evolution of the word "science" in English, see the assessment by Williams (1983). In his latest book on the history of technology, Joel Mokyr distinguishes this kind of "useful" knowledge, which he calls "propositional" and which, according to him, is related to beliefs, from "prescriptive" knowledge, "which we may call techniques". Cf. Mokyr (2002), pp. 4-15.

the 1780s and 1850s, vaguely relating it to the great political, economic, social and intellectual changes which occurred in those years, and sketching a similarity between the specialized production of new kinds of knowledge by the emerging scientific laboratories of those times and the coeval production of all kinds of special commodities by their expanding factories.

These same issues were taken up again by Cunningham five years later in a coauthored article[8], situating the aforenamed "invention" between the years 1760 and 1848, taking as an empirical and theoretical landmark the revolutionary period analyzed by the first volume of the well-known series of books by Eric Hobsbawm[9]. In their article, Cunningham and Williams emphasized the occurrence during that period of three simultaneous revolutions: the economic of the First Industrial Revolution, the political represented by the American and the French Revolutions, and the intellectual inaugurated by Kant at the end of the eighteenth century.

Reminding us that present-day historians of science have definitely ceased to believe in the existence of a unique scientific method inducing the convergence of all disciplines to the principles and findings of the physical sciences, as well as in the equivalence of freedom of thought with material prosperity, and in the presence of such attributes at all times and places, their article turned to the specific discussion not only of the precise delimitation of the epoch in which the emergence of the modern sciences occurred, but also to the identification of the origins and mechanisms which preceded their formation. By doing this, the authors denied categorically that such emergence and formation could have happened at the time and in function of the sixteenth and seventeenth centuries' Scientific Revolution, stressing that the traditional historiography of the latter has always been fundamentally centered on the present, instead of focusing on the periods in question according to their own characteristic features and values[10].

Cunningham and Williams pointed out that only in the first decades of the nineteenth century was the term "science" begun to be used universally in its present sense, designating the kinds of knowledge and of activities that we nowadays associate with it. These kinds of knowledge and activities were then as recent as the word which went on to designate them. They did not correspond to pre-existing knowledge and to activities undertaken with other denominations, as one could have inferred from the coetaneous emergence and diffusion of the word "scientist" in the

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8 Cunningham & Williams (1993).

9 Hobsbawm (1962).

10 The Authors'criticism was specifically directed to historical syntheses like those of Butterfield (1949) and Hall (1983), whose first edition, published in 1954, had been more adequately entitled as *The Scientific Revolution 1500-1800: the transformation of modern scientific attitude*.

English language (a word which also exists in Portuguese —*cientista*— but has no equivalents either in French or in Spanish)[11]. It was also during those years that there began to appear other neologisms and new agents like "biology" and "biologist", "geology" and "geologist", and even "physics" and "physicist", at the same time that new meanings were being given to the traditional notions of "astronomer", "chemist" and "mathematician"[12].

Before the advent of the present-day sciences, there only existed some similar knowledge and activities in the fields of natural history, in "mixed"(or applied) mathematics and, above all, in the so-called natural philosophy. The meanings attributed to them at those times by the people who performed and developed such activities have not been hitherto sufficiently investigated, and sometimes they have even been grossly falsified, as in the case of an English title of Isaac Newton's famous work of 1687, translated into *Mathematical Principles of Natural Science* from the Latin original *Philosophiae Naturalis Principia Mathematica*.

A complete "mathematization" or modern "scientification" of Newton's physics did in fact occur, but much later, at the beginning of the nineteenth century, through the *Traité de mécanique celeste* of Pierre Laplace (1749-1827). In Newton's *Principles* themselves, as Cunningham recalled in another article, we can find the explicit belief that the study of natural philosophy represents a bulwark against the progress of atheism[13]. Similar and converging observations had been made a long time before by the economic historian George Clark in an article published in 1936 in the *Economic Journal* and reproduced as a chapter of his book one year later[14].

In spite of being formally separated from theology, natural philosophy in Newton's time, and also during the whole first part of the eighteenth century, still remained harnessed to the objectives of explaining the world's origins, as well as the causes of its natural phenomena and processes. Because of this, we should not refrain from ascribing the proper relevance to the meaning of changes in nomenclature and contents which have occurred since then, and also from the identification of the moment and the ways in which they occurred and started their diffusion and intensification through time and space.

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11 With respect to this, see the article by Ross (1962), according to whom the creation of this neologism in English reflected the transition of scientific activities predominantly undertaken by amateurs to the specialized realm of professionals, and by Hahn (1975), who reminds us that in French the word *scientifique* "used as a substantive" (equivalent to the Spanish term *científico*) did not become usual before the twentieth century.

12 Cahan (2003), Chapters 1 and 10.

13 Cunningham (1991).

14 Clark (1970). See also in this regard the considerations by Gabbey (1990).

These important changes in the field of scientific knowledge and activities only begin to be increasingly observed during the first years of the nineteenth century, mainly in France and in Germany (then still not a unified country). They coincided in time and space with the growing professionalization and secularization of scientific and technological research, whose main initial stages had taken place not so much in the universities and other centers of higher education as in the academies of science which began to multiply everywhere in Europe and the Americas from the second half of the nineteenth century, as did several astronomical observatories and botanical gardens, and even some governmental departments linked to the armed forces, to the exploitation of mines and other natural resources, and to the various countries' transport and communications infrastructures.

And this was so because, in social and economic terms, any professionalization process requires the preliminary, or at least the simultaneous, emergence of a market —that is, of a demand for and a supply of specific goods and services, as well as of the people and organizations able to provide and/or acquire them. The market in question was a typical case of the demand for and the supply of specialized knowledge and activities, as well as the human and material resources needed for their provision and utilization. Accordingly, this supply and demand was mainly and fundamentally generated by the development of the eighteenth century's national states, and also increasingly by some emerging and growing industries both in the public and the private sectors of the economy. These were the processes that formed the context in which there began to take shape and to consolidate the initial relationships between scientific and technical progress (with the latter being moved and conditioned by the development of technology), and between these and the progress (or development) of national macro and micro economies. Our task from now on is to determine and specify how and why this occurred at that time and not before.

## 3. Periodization of an Economic History of Science and Technology

Despite having situated such changes almost exclusively in the nineteenth century, and of having repeatedly emphasized the universities conservatism, a good starting point for this can be found in Everett Mendelsohn's pioneering work of the 1960s, which pointed to the gradual disappearance, during the second half of the previous century, of the so-called natural philosophers and to their progressive substitution by specialized professionals devoted to the study of ever more limited subjects[15].

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[15] Mendelsohn (1964). More recently, similar views have been presented by Joel Mokyr in his chapter on "The Industrial Enlightenment: the taproot of Economic Progress". Mokyr (2002), pp. 28-77.

These trends, according to him, were mainly due to the increasing expansion and complexity of available knowledge, an evolution by which the formulation of relevant theories and the realization of meaningful experiments were increasingly becoming activities which were only within the reach of specialists working full-time on such problems and being adequately remunerated for it. In this context the era of dilettantism and of encyclopedic knowledge was already being left behind and yielding space to the domains of increasing specialization. In the course of time both the sectorial economic organizations and the regional and national political and administrative entities had to adapt to this new situation.

It is important to note that very similar observations were being made in 1776 by Adam Smith in the opening chapter of *The Wealth of Nations*, where he stressed, using the terminology of those times that:

> "All the improvements in machinery, however, have by no means been the invention of those who had occasion to use the machines. Many improvements have been made by the ingenuity of the makers of the machines, when to make them became the business of a peculiar trade, and some by that of those who are called philosophers or men of speculation, whose trade it is not to do anything, but to observe everything; and who, upon that account, are often capable of combining together the powers of the most distant and dissimilar objects. In the progress of society, philosophy or speculation becomes, like every other employment, the principal or sole trade and occupation of a particular class of citizens. Like every other employment too, it is subdivided into a great number of different branches, each of which affords occupation to a peculiar tribe or class of philosophers; and this subdivision of employment in philosophy, as well as in every business, improves dexterity, and saves time. Each individual becomes more expert in his own peculiar branch, more work is done upon the whole, and the quantity of science is considerably increased by it"[16].

This long citation of Adam Smith's classical and well-known considerations on the division of labor confirms Mendelsohn's theory about the increasing fragmentation of natural philosophy during the eighteenth century combined with a progressive specialization and professionalization of its practitioners. It also reveals the emerging links between technology and the sciences already occurring in the second half of that century[17]. These links though, may have been more visible in Britain than elsewhere, due to the advent in that country of the First Industrial Revolution. And perhaps for this reason another part of Mendelsohn's study refers precisely to the

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16 Smith (1937 [1776]).

17 A more recent and quantitative confirmation of this can be found in a survey by Gascoigne (1995).

dynamism of British technology, contrasting it with the slow, discontinuous and asystematic progress of science at the same period on the European Continent, more particularly in France and in Germany.

### 3.1. The case of Britain

During the second half of the eighteenth century, there had been a decentralization of English scientific activities and organizations from London to the manufacturing cities of the Midlands, with the establishment of scientific academies and societies in towns like Leeds, Birmingham, Bristol, Newcastle and Manchester, reinforcing within them the relationships between science and technology, thus giving origin and substance to the utilitarian and productivistic character of the following century's discourses on science. Such trends described by Mendelsohn had already been detected and characterized a little earlier by other authors, like Robert Schofield in relation to Birmingham's Lunar Society[18], and A.E. Musson & E. Robinson with regard to the Literary and Philosophical Society of Manchester[19].

The nucleus of the former (which lasted until 1791) had been established around 1760 through the meeting and immediate friendship between Matthew Boulton (1728-1809), the entrepreneur who would later become James Watt's partner in the production and commercialization of steam engines, and the natural philosopher Erasmus Darwin (1731-1802), grandfather of the famous naturalist Charles Darwin. According to Schoefield's report, the Birmingham Society, which had among its other members the chemist and Unitarian pastor Joseph Priestley (1753-1804) and the ceramic entrepreneur Josiah Wedgewood (1750-1795), was above all a group of friends living close to each other, meeting almost every day and/or corresponding among themselves at least once a week[20]. Their formal monthly gatherings were less important than the joint activities which they periodically undertook, and which enable us to classify the Lunar Society as an informal technological "think tank" of those days, by whose performance one can infer that, instead of the sciences orienting that epoch's industrial development in England, it was the latter which provided new elements for a continuing progress of the emergent scientific disciplines.

Such an assertion has been made by Arnold Thackray with regard to Manchester's Literary and Philosophical Society[21]. Formally created in 1781, it counted

18 Schofield (1957).

19 Musson & Robinson (1960).

20 On these other two participants, see Shoefield (1959 and 1967).

21 Thackray (1974).

among its members the chemist and physicist John Dalton (1766-1844)[22]. Starting from discussions on the technical problems of the times, mainly but not only the ones related to the town's textile manufacturing industry, the organization soon began to offer extension courses in areas of industrial interest, like those of the bleaching and coloring of textiles. Several of its members also undertook the translation of French and German works both on these subjects and also of a more general scientific interest, as well as the translation to foreign languages of the Society's *Memoirs*. These ancillary activities gave rise to numerous technical publications, contributing to enrich the contents of Manchester's public library, the oldest of its kind in England. They also led to the foundation of Owens College, which would later become the University of Manchester.

### 3.2. And that of France

The relationship between science and industry in France during the same period did not have similar characteristics and was subjected to a quite critical assessment by Charles Gillespie, published half a century ago[23]. According to which, within the economic history of industries such as textile manufacturing, there was no difficulty in perceiving on the one hand that the French had a good deal of catching up to do in relation to Britain, and on the other that France's production maintained only scant and indirect links with the local scientific developments of that age. As a student of the invention of Nicolas Leblanc's process for the manufacturing of soda, he had shown that this invention did not result from any original and well-founded theoretical inspiration, but from the fallacious conception of an analogy of the chemical reactions of that process with those of the smelting of iron ore[24]. Gillespie also stressed that subsequently neither the inventor himself nor other French producers of soda of those times who were using Leblanc's process, showed any interest in finding out the real nature of the chemical reactions that it involved.

Because of such episodes, Gillespie strongly recommended in his articles not only the cautious use of any official reports produced at that and at later times, but also the keeping in mind of the differences which exist between the exploration of available scientific knowledge by inventors, tinkerers or manufacturers, and the conscious utilization of the same knowledge for the solution of concrete problems in given productive processes. And, in relation to the latter, he also stressed that only

22 On the latter, see Thackray (1970).
23 Gillespie (1957a).
24 Gillespie (1957).

rarely has the most advanced knowledge come to be used. This knowledge, obtained through arduous and complex scientific or technological research, can frequently remain for a long time on the margin of current productive processes.

It is interesting to note that, in subsequent writings[25], this same author spared no praise for the performance of French science, pointing out that during the period between the revolutions of 1789 and 1830, the scientific and technological communities of that country had definitely left behind the generic attitudes of the eighteenth century Enlightenment's natural philosophy, assuming at once the principles and categories of the modern scientific disciplines that were to emerge during the first decades of the nineteenth century[26]. This leap to modernity, as we know, did not occur without institutional upheavals and without affecting, sometimes tragically, the fate of the people involved. But the overall results of these changes could not have been more favorable in all scientific fields, either in terms of the innovations which were generated (such as, for example, the establishment of the decimal metric system), or in relation to the production of great numbers of top level scientists and engineers, all destined more to public service occupations than to staff the economy's private sector.

Such advances were promoted and accompanied by the development of France's higher education system, whose establishments began to attract an increasing number of foreign students and also served as models for similar initiatives in other countries. Through the scientific treatises and other publications elaborated by their teaching staff, we can sense how in that period the French schools had become the place where, for the first time in history, most of the best and more active scientists and technologists could become university professors, in this way gaining entry into the country's cultural and professional elites.

But after this period these developments did not prevent France from losing her scientific leadership to Germany, while at the same time continuing to be unable to improve her economic and technical performance *vis-à-vis* her competing rivals. The outcome, however, is not of major interest within the present paper. More important for our specific current purposes is Gillespie's assessment of that period's secular evolution in the fields of science and technology. The latter continued to be dominated by Britain, having the steam engine as its mainspring. Britain's economic development had already begun to accelerate in the previous decades, before and during the Napoleonic wars, which were also a time of significant mechanical inventions

[25] Gillespie (1965 and 1983).

[26] In the second work mentioned above, Gillespie adopted as chronological landmarks D'Alembert's (1717-1783) last years and the death of Laplace in 1827, pointing as well to the emergence of Auguste Comte's positivism.

and improvements in the manufacturing sector[27]. The various sciences in turn were gradually extending their reach and scope, while at the same time constantly reducing their individual perspectives and deepening their respective approaches.

The ever increasing number of specialized scientific disciplines was accompanied by a growing mathematization of their contents in all fields, by the transformation of laboratories into classrooms for the teaching of experimental subjects, by the establishment of amphitheatres for demonstrations, particularly but not only in the schools of medicine, and by the incorporation of discussion seminars into the didactic procedures of universities and other tertiary education centers. All these innovations involved profound changes, quantitative and qualitative, pertaining to the teaching and learning of every discipline in turn, and giving rise in several cases to the emergence of new ones, either through amalgamation or by the splitting of already existing ones. It was the sum of all these transformations which produced the fragmentation and gradual disappearance of natural philosophy, and a little later also of natural history, as well as their equally progressive substitution by our present-day modem scientific disciplines, within a process that some authors have defined as the occurrence of a "Second Scientific Revolution" —a subject which I will not discuss at this moment[28].

A more relevant issue stems from the three attributes presented by Gillespie at the end of his 1983 essay for establishing the existence or not of a profession, namely:

a) the involvement of an association, more than a mere occupation, "whose practice presupposes mastery of a body of knowledge, and thereby qualifies for the prestige attaching to the cognitive"
b) the economic character of an occupation "legitimately followed for gain, and not a status held of right"
c) a self-governing "jurisdiction over the education, qualifications and conduct of its members, usually by tacit or actual delegation from the State, supposedly in accordance with the public interest"[29]

According to the author, before the French Revolution, these three attributes could only be associated with the clerical, juridical and medical professions; both the emerging scientific disciplines and the natural philosophy or natural history that had preceded them possessed at most only the first of these attributes. The people devoted to scientific and technological pursuits only began to acquire the other two

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27 See also in this regard McKie (1965).
28 For a critique of this concept, see the valuable article by Schaffer (1986).
29 Gillespie (1983), p. 36.

from the end of the eighteenth century on, with the creation in France of new educational institutions, such as the École Polytechnique, founded in 1794, and the École Normale Supérieure, established in the following year.

Although they were new and innovative, these and other institutions of the same kind (founded later and/or in other countries) did not emerge suddenly and nor were they a bolt from the blue. It is always useful to remember that institutionalization, or the establishment of institutions, always constitutes a process, and not a single isolated event or phenomenon. Being a historical process, it has its roots and antecedents in the past, and always takes time to be completed. Moreover, it always involves people and groups capable of conceiving, formalizing and consolidating institutions, as well as people and groups acting contrariwise, preventing the existence of these institutions or making it difficult, and so hindering and delaying the process. And neither do these people suddenly just appear from nothing. This aspect of the question has been well illustrated for the French case in some seminal articles by Maurice Crosland (1975, 1977, and 2007).

In other words, to know the origins and to understand the significance of any institution, we need, even more than to comprehend any isolated events or phenomena, to recede in time, in order to glimpse and reconstitute its initial trajectory. In the present case, such a procedure is part of and constitutes an important aspect of the equating of our periodization problem, related to the formulation of an economic history of science and technology of the most developed countries of the present, whose study has to do specifically with the evolution through time of the changing relationships between the scientific and technical progress of those countries and their economic development.

## 4. Universities and Schools of Engineering

In earlier parts of this essay, we linked the emergence and formation of these relationships to the professionalization of scientific and technological research, which, as we have already noted, began simultaneously in different institutional environments. In order to complete our argument, we shall now highlight the analysis of two of them during the eighteenth century, namely the universities which originated in previous centuries, and the schools of engineering, the first of which were created precisely in that century. Not by chance, both are related to the tertiary education of the people and groups who either facilitated or hindered the aforenamed institutionalization process, and whose transformations through time reflected, direct or indirectly, with or without some delays, the evolution of available scientific and technological knowledge.

### 4.1. European and North American Universities

Our analysis of the eighteenth century's university environment is based upon a recent work by Laurence Brockliss on the teaching of physical and natural sciences in the higher education schools and colleges of Europe and the Americas[30]. Seen as a whole, the structure of the teaching did not appear to change much during that century. The total number of students enjoying it probably remained much the same. Despite the demographic growth on both sides of the Atlantic, the system only seems to have expanded more visibly in the English-speaking countries: in North America from the foundation of Princeton in 1746, and more particularly after the independence of The United States thirty years later; whereas in Britain, due to the lack of access by non-Anglicans to the universities of Oxford and Cambridge, there occurred the creation of numerous independent academies, parallel to the official system, and which continued to exist well into the nineteenth century, only disappearing after the mentioned restrictions had been definitely removed[31]. And on the European continent the sole important event was the establishment in 1733 of the University of Göttingen, whose qualitative impact will be mentioned again later. In general terms this level of education continued to be the exclusive preserve of the elite younger generations of male students.

As in previous centuries, the universities were usually made up of four faculties —those of arts, theology, law and medicine— with the studies related to nature being shared between the first and the last of them. Within the arts faculties, which also provided the courses in mathematics, these studies were a part of the courses in philosophy, consisting of its four traditional disciplines: logic, ethics, physics and metaphysics. The order of presentation of the last three tended to change through time, but the teaching of logic always maintained the first place, as a gateway to the other disciplines.

According to the Aristotelian conception which had prevailed since medieval times, physics, or the science (that is, the knowledge) related to natural bodies, was an analytic-deductive discipline, similar to those of ethics and of metaphysics. During the seventeenth century these millenary conceptions had been slowly eroded and substituted first by Cartesian mechanism, and later on, by the mathematical and/or experimental Newtonian philosophy of nature. On the other hand the more direct knowledge of natural phenomena was provided in the medical faculties through courses in descriptive and classificatory disciplines like anatomy, botany

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30 Brockliss (2003).

31 On the latter, see also chapters I and VII of the classical study by Hans (1951), whose data were reproduced, among others, by Inkster (1991) pp. 35-36.

and chemistry. Such disciplines at that time were still barely formalized and held only a subsidiary role in medical teaching, which concentrated on the studies of physiology, pathology and therapeutics, as it does nowadays.

The curricular and programmatic organization of all these disciplines had also remained much the same. The students continued to have to prepare for their university learning through studies of Latin and Greek. In the arts faculties, the teaching of physics continued to be linked to the other philosophical disciplines, and frequently all the four were taught by one and the same professor. This apparent lack of formal changes, *vis-à-vis* the plethora of new knowledge which had issued from the sixteenth and seventeenth centuries' Scientific Revolution, reflected the fundamentally conservative viewpoint of the official elites that were responsible for the universities' maintenance and administration, and which were linked to the states and/or to the prevailing religious denominations.

According to these authorities, the teaching of the universities should have as its main objectives the preparation of professionals for the Church, the Judiciary and other areas of public administration, and for the health care of at least the members of the elite. All this could continue to be achieved through a solid classical education, the generic teaching of the different branches of philosophy, and a variable in-service professional training through the practice of the graduates' respective vocations, without any necessity of enlarging or deepening the already available physical and natural knowledge.

Nevertheless, in contrast to what had been the case until then, these viewpoints were no longer just passively accepted within the universities. As time went on, alternative proposals began to be formulated and adopted, based upon the new knowledge provided by the scientific discoveries of previous epochs and of the eighteenth century itself, aimed at modifying the scope and duration of the mathematical and natural philosophy studies in the faculties of arts. By the middle of the eighteenth century the leadership of this movement was formally assumed by the French encyclopedists, and around 1790 its echoes were already being heard all over Europe, although its more concrete effects would acquire a greater visibility only at the beginning of the nineteenth century, from the time when in France all traditional universities were suppressed and replaced by new institutions of higher learning. These events, as is well known, helped to influence the emergence of similar or related occurrences, phenomena and processes in other countries. But even before that the conditions for the changes inherent to all of them had already begun to be created by people and groups pervaded with purposes that were to become ever more consistent and manifest through time.

Until the beginning of the eighteenth century, theology had been considered the "queen of the sciences" —i.e. the main form of possible knowledge— a reason for which the theological faculties continued to be the most important in all universities, even if the numbers of their students were inferior to those of the law and of the arts faculties. At that time the students of medicine were still not very numerous, thereby contributing to the fact that questions linked to live beings remained relatively undiscussed. In the faculties of arts, the philosophical studies in general had mostly a propaedeutic function, aimed at preparing the best students for their theological learning, particularly taking into account the circumstance that legal studies did not always require a previous and complete education in arts. In this context all the philosophical disciplines, including physics, had to converge into theology, without any opposition to the principles of religious orthodoxy, and with the task of contributing to provide it with the concepts and logical instruments to enhance its revealed truths, and also with extra-biblical elements and arguments to improve the understanding of the world's divine creations.

But at that very time the relationships between philosophy and theology began to be questioned particularly in the Protestant states of northern Germany, within a trend foretold by the creation of the University of Halle in 1693, and completed forty years later by the already mentioned foundation of the University of Göttingen, the first multidenominational establishment of Europe. As it could have been expected, this new university soon attracted to its staff some of the times' main exponents in the fields of mathematics, medicine and natural philosophy, thus also becoming *ipso facto* the first research university in history.

Its model and example was soon followed by other German universities of the same region, such as those of Helmstedt and Leipzig, which, in the second half of the eighteenth century established a course in mathematical analysis together with the creation of the first scientific journal exclusively devoted to that discipline. And, at the end of that same century, both natural philosophy subjects and some natural history disciplines had already managed to enlarge considerably their specialized areas of activities within the region's existing university system. As a proof of this we can mention the case of the philosopher Immanuel Kant (1724-1804), who in 1798 at the Eastern Prussian University of Königsberg, after having taught numerous classes in physics, published a work entitled *Streit der Fakultäten* (*The Dispute of the Faculties*) in which he proposed the establishment of faculties of philosophy (instead of arts) that would be independent both of the other faculties and of governmental and/or ecclesiastic supervision, an idea that would be put into practice ten years later by one of his disciples, Wilhelm von Humboldt (1767-1835) at the foundation of the University of Berlin.

Although less conspicuous than those of northern Germany, similar transformations did occur as well in other parts of Europe, especially with regard to the teaching of physics. Following the discipline's progressive enlargement and consolidation, as well as the support it began to receive from national governments through the establishment and functioning of an increasing number of official scientific academies, the teaching gradually ceased to be directed towards the causes and effects of aprioristic fundamental principles, turning instead to the analysis and explanation of nature's phenomena and laws. And this was made possible both through the instrumental use of mathematical categories of analysis and, perhaps mainly, by the incorporation into the teaching of experimental procedures.

In several Catholic countries the new orientation was directly introduced by governments after the expulsion of the Jesuits, a process initiated in 1758 in Portugal by the marquis of Pombal. In France, for instance, during the second half of the eighteenth century, natural philosophy courses were replaced by courses in mathematical physics, and this was the case in all the faculties of arts of the country, thus yearly enabling hundreds of students to attend classes in this essentially quantitative and increasingly technical discipline. It was in this manner and in such an environment that the young Pierre Simon de Laplace first came into contact with Newton's ideas at the end of the l760s.

At the same time that these quantitative and qualitative transformations were taking place in the teaching and learning of physics, by which mathematics itself began to be changed and was becoming an ever more specialized discipline, there was a dramatic expansion in the chemistry courses offered by the schools of medicine, whose student ranks grew continuously and considerably throughout the eighteenth century; particularly in France, these courses ceased to be sporadic and subsidiary, and while gradually increasing their degree of formality, they soon became permanent. With the passing of time and through the contributions of exponents like Lavoisier (1743-1794) and Berthollet (1748-1822), chemistry rapidly ceased to be a merely descriptive discipline and became more and more analytical and experimental, with applications in both agriculture and industry. Although for somewhat different reasons, the same trends could also be observed in Germany[32].

Also within the medical schools, several other descriptive and subsidiary disciplines —such as geology, botany and zoology— were also being transformed at that time. Initially grouped together in a single field called natural history, at the beginning of the nineteenth century, they gradually expanded, and successively acquired an identity of their own, thus becoming new autonomous and experimental sciences[33].

With regard to the eighteenth century's formative age here being examined, it has to be stressed that with the emergence and expansion of the subjects being taught at the new universities in the fields of physics, chemistry and natural history,

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32 See the excellent study by Homburg (1999).

33 On its origins and development, see the essay by Sloan (1990).

these subjects began to require official investments for the acquisition of scientific laboratories and instruments, as well as collections of mineral, plant and animal specimens. During the last decades of the century such investments coincided in time and space with the lengthening of the medical courses (from the previous three to four years to the present day five to six years), which were also improving both in theoretical and practical aspects, linking anatomy to physiology, and strengthening the connections between pathology and therapeutics.

Apparently the changes that we have been describing until now only arrived at a later date in the United States[34]. But the conditions for these changes also seemed to have been there from earlier times, as has been recently noted by Sara Schechner:

> "Americans had high regard for higher education, and by 1780 there were eight colleges actively teaching science. Listed in the chronological order of class room instruction, they were Harvard, Yale, William and Mary, Princeton, King's (later Columbia), the College of Philadelphia (later the University of Pennsylvania), Rhode Island (later Brown), and Dartmouth. In 1638, Harvard students learned natural philosophy, botany, astronomy and mathematics. These laid the groundwork for surveying, navigation, mensuration, geography, horology, and later Newtonian philosophy. Fluxions (calculus) made a noteworthy appearance first at Harvard and Yale. Botany was dropped, but reappeared along with zoology and chemistry near the end of the eighteenth century at colleges that had medical schools (namely Philadelphia, King's and Harvard)"[35].

And the same author also added that these conditions did not differ substantially from what was then happening in Europe, more particularly in England:

> "...at the close of the colonial period, students spent 20 to 40 per cent of their time on science instruction. The aims of these studies were both utilitarian and philosophical. It was expected that scientific knowledge not only would help students to become productive citizens, but would also teach them how wisely God had designed the universe"[36].

These mostly present-day impressionistic observations could perhaps also have taken into account the limits imposed upon the situation by the colonial status of North America until the end of the eighteenth century and by the excessive reliance of its intellectuals on English scientific knowledge. According to Dirk Struik, England's most advanced exponents of those days, like John and William Hunter,

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34 Daniels (1967).
35 Schechner (2001), p. 498.
36 Ibidem.

anatomist and surgeon, Stephen Hales, Joseph Black and Joseph Priestley, chemists, had considerable influence on American science, but mainly after the Revolution. While some other European authors were also being read and studied there:

> "the enormous development of continental mathematics and its influence on astronomy and mechanics, due to Leibniz, the Bernouillis, Euler and Lagrange and their followers, remained entirely unknown in the Colonies…"[37] .

Such circumstances were to change after Independence, yet this did not happen at once or easily, as can be grasped from the initial pages of Hunter Dupree's well-known study, according to which:

> "The new country did not entirely lack institutions of its own. The American Philosophical Society in Philadelphia had much to offer besides the accomplishments of Benjamin Franklin… Boston, under the influence of John Adams and the wartime alliance with France, had established its American Academy of Arts and Sciences... Within the framework of natural philosophy and natural history, the particular fields of physics and chemistry, botany, zoology, and mineralogy were clear, but nobody imagined that a man should devote his whole time to one of them. Indeed, almost none of the members were even professional scientists. Many were doctors, lawyers or clergymen, making their living and spending much of their time in ways unconnected with science. Medicine provided perhaps the nearest approach to a scientific profession. But the physician of that day had no scientific basis for much of his work, and the research he did was usually collecting objects of natural history..."[38].

> "Although the colleges that were inherited from colonial times helped somewhat in providing centers of learning and equipment and employment for scientists, these benefits were largely casual and unplanned"[39].

Continental Europe was then more advanced in this respect, and the transformations undergone by its universities, despite having been slow, tardy, and sometimes difficult to perceive in the short term, ended up generating ample and profound effects through time, denying in part the immanent conservatism attributed to them both by Everett Mendelsohn and Adam Smith[40]. At the same time it is important to

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37 Struik (1991), pp. 54-55.
38 Dupree (1986), p. 7.
39 Idem, pp. 8-9.
40 Cf. his comments in book V of *The Wealth of Nations* (second article of part III in chapter I) entitled "Of the expence of the Institutions for the Education of Youth", p. 716 and ff. of the edition mentioned in note 14.

add that they were not alone in the field of higher education in promoting, already in the eighteenth century, the beginning of scientific and technological research's professionalization, as well as the establishment of incipient relationships between scientific and technical progress, and of both of these with economic development on the micro and macro level. Thus, we also have to mention what was occurring at that same time in relation to the creation and expansion of the first schools of engineering.

### 4.2. French and German Schools of Engineering

With regard to the emergence and evolution of these, besides continuing to rely on Brockliss'work, we shall also be using the valuable information contained in an older study by Peter Lundgreen, who compared the scholarly training of engineers promoted by governments of Continental Europe (France and Germany) with that which emerged later through private initiatives within the Anglo-American context (of Britain and the USA)[41]. Considering the subject and the objectives of the present essay, we shall limit ourselves to discuss here what happened during the eighteenth century in relation to the first case.

Both at the time of the French *ancien régime* and during several decades after the Revolution, the word *ingénieur* was fundamentally used to designate a special category of public servant, the "state engineers", either those linked to the armed forces, and thus pertaining to the *génie militaire*, or the ones involved in the elaboration of projects and the construction of civilian works —such as bridges, roads, canals, governmental buildings etc., who were members of the *génie civil*. The professionals of the former category had been initially educated by the military academies designed to train artillery and procurement officers, the latter being familiar with the building of fortifications and the establishment of transport and communication infrastructures needed to facilitate the displacement of land and naval forces.

In either case, these were professions whose origins went back to the sixteenth and seventeenth centuries' advances in military technology and strategy, and whose activities, due to technical progress were becoming ever more complex and perfectible. The same applied to the civilian areas, which were gradually requiring a more refined education from their practitioners, especially in relation to mathematics (calculus and geometry) and also in fields linked to physics, to chemistry and to the mineralogy of the various building materials. These were the factors which ultima-

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41 Lundgreen (1990).

tely led to the foundation of the École des Ponts et Chaussées between 1747 and 1775, as well as to that of the École du Génie et de l'Artillerie from 1748 to 1755. The teaching in both was based upon advanced mathematics, whose high level even led to the pioneering formulation of a descriptive geometry by the young Gaspard Monge (1746-1818), at the time professor at the military École du Génie.

In contrast to what continued to occur at the traditional military academies, neither the teachers nor the students of these new schools were exclusively or preferentially recruited among the ranks of the aristocracy. At the same time their graduates enjoyed a wide social prestige due to the high level of the technical qualifications obtained on the completion of their studies. For this reason they became entitled to perform various functions and to occupy different posts in the French public administration already in the period preceding the Revolution. And, after 1789, contrary to what occurred at the universities, closed down by the new regime, the engineering schools not only continued to thrive but were even strengthened by the already mentioned creation of the École Polytechnique of Paris, followed by the recreation of the École des Mines (originally established in 1783), and by the emergence of France's famous network of *grandes écoles*, a system that, from the nineteenth century on increasingly became geared to the scientific and technical training of the elite, while the university system, reintroduced by Napoleon between 1804 and 1808 on a national state basis, became entrusted only with the task of educating the middle range professionals needed to promote and maintain the country's economic and social development.

For their part, the schools of engineering that were being established in different parts of Germany (and also in Austria) throughout the eighteenth century presented several analogies with the French system, and initially were strongly influenced by them, as can be seen by the incorporation into the German language of the French term *ingénieur*. In Prussia, the creation of a corps of military engineers was accompanied in 1755 by the foundation of an *École du Génie* (sic), later restructured under the name of *Ingénieurakademie* (in 1788). Something similar occurred with the Austrian *Ingénieurakademie*, founded already in 1717 and reorganized with the same name sixty years later.

Outside military circles, the profession was made up of civil and mining engineers. The schools where the latter were being trained, particularly the Saxonian *Bergakademie* of Freiburg, founded in 1765, were held in high esteem throughout Europe. Prussia also established a school for mining engineers five years later, but her most original contribution was probably provided by the *Bauakademie* established in 1799 and encompassing within the same unit the teaching of civil engineering and that of architecture. The graduates of these schools did not receive the title of *ingénieur*, but were called respectively *Baubeamte* or *Bergbeamte* (public servants of construction or of mines), and, as a matter of fact, they never attained the same level of social prestige as their French colleagues, mostly performing subaltern functions and occupying posts of lesser importance in the public administration of the various German states at the end of the eighteenth century and during the first decades of the nineteenth.

This feature became reflected in the quality of the courses imparted by such professional schools, which in consequence, and contrary to what occurred in France, remained in a position of inferiority *vis-à-vis* the German universities. And this situation would only be changed from the 1850s on, with the expansion and consolidation of the *Technische Hochschulen* (the German speaking countries' polytechnic schools), through which the training of engineers in Germany finally attained the same legal status and the same social prestige as that of the universities, a change which in part was aided by the advent of the Second Industrial Revolution, and which in part contributed to accelerate it.

## 5. Main Conclusions

Having completed our exposition of the periodization problem of the economic history of science and technology in today's richest and most developed countries, we may now be able to present the following partial and preliminary conclusions:

a) It seems acceptable to adopt the second half of the eighteenth century as a starting point for the economic history of science and technology of these countries. This is not due only to the occurrence at that time of various simultaneous revolutions (in the political, economic and intellectual fields), a factor emphatically pointed out by Cunningham and tacitly accepted as important by most of the other authors mentioned in this essay, but it is also due to the effects already felt at that time of the gradual professionalization of scientific and technological research, induced by the progressive formation and institutionalization of the modern scientific disciplines derived from the decomposition of Newtonian natural philosophy and from the consolidation of different branches of natural history occurring in the same years.

b) These two processes were generated and accelerated by the transformations through time of the teaching of these subjects, both within the traditional environment of the universities and through the establishment in that period of the first higher education schools of engineering. It was around these changes that first began to occur and multiply the relationships between scientific and technical progress, and of both of these with the micro and macro development of the economy, which are at the center and constitute the main subject of any economic history of science and technology.

c) The essence of all historical processes resides in the emergence and consolidation of new structures (or sets of relationships), as well as in the contention, overcoming and substitution of preceding ones. From this perspective, the economic history of science and technology of today's richest and most developed countries is not necessarily concerned with the differences that exist between the contemporary scientific disciplines and the past's natural philosophy and/or natural history; it would be well to consider the latter as precursors of the former.

d) The most important issues of our history's periodization relate to the epoch(s) when the aforementioned transition occurred, and to the reasons why and to the ways in which it did occur. This is something that can only be determined through the combining of the internalist perspectives of scientific and technological thought's evolution with the externalist framing of the context of that evolution, in order to identify its connections with other historical transformations of economic, social and cultural life, and principally by inserting or reinserting it within the totality of historical development.

## References

BROCKLISS, Laurence (2003): "Science, the Universities and Other Public Spaces: teaching science in Europe and the Americas", Roy Porter (Ed.), *Eighteenth-Century Science*, , *The Cambridge History of Science*, Chapter 3, Vol. 4, Cambridge University Press, pp.44-86.

BUTTERFIELD, Herbert (1949): *The Origins of Modern Science 1300-1800*, London, Bell.

CAHAN, David (2003): "Looking at Nineteenth-Century Science: an introduction", *From Natural Philosophy to the Sciences: writing the history of nineteenth-century science*, Chapter l, University of Chicago Press, pp. 315.

—(2003a): "Institutions and Communities", *From Natural Philosophy to the Sciences: writing the history of nineteenth-century science*, Chapter 10, University of Chicago Press, pp. 291-328.

CLARK, George Norman (1970): "Social and Economic Aspects of Science", chapter II of *Science and Social Welfare in the Age of Newton*, reprint of the 1949 second edition, Oxford University Press, pp. 60-91.

CROSLAND, Maurice (1975): "The development of a professional career in science in France", *Minerva*, 13(1), pp. 38-57.

—(1977): "History of science in a national context", *British Journal for the History of Science*, 10, pp. 95-113.

—(2007): "The financial support of men of science in France c. 1600-c. 1800: a survey", *History of Science*, XLV, pp. 327-355.

CUNNINGHAM, Andrew (1988): "Getting the Game Right: some plain words on the identity and invention of science", *Studies in the History and Philosophy of Science*, 19(3), pp. 365-389.

—(1991): "How the *Principia* got its name, or taking natural philosophy seriously", *History of Science*, XXIX, pp. 377-392.

CUNNINGHAM, Andrew and WILLAMS, Perry (1993): "Decentring the 'Big Picture': *The Origins of Modern Science* and the modern origins of science", *British Journal for the History of Science*, 26, pp. 407-432.

DANIELS, George H. (1967): "The Process of Professionalization in American Science: the emergent period, 1820-1860", *Isis*, 58, pp.151-166.

DUPREE, A. Hunter (1986): *Science in the Federal Government: a history of policies and activities*, Baltimore, Johns Hopkins University Press.

FULLER, Steve (2000): "Internalism *versus* Externalism" in HESSENBRUCH, Arne (ed.), *Reader's Guide to the History of Science*, Chicago, Fitzroy Dearborm), pp. 380-381.

GABBEY, Alan (1990): "Newton and Natural Philosophy" in OLBY, R.C. et alii (eds.), *Companion to the History of Modern Science*, Chapter 16, London, Routledge, pp. 243-263.

GASCOIGNE, John (1995): "The Eighteenth-Century Scientific Community: a prosopographical study", *Social Studies of Science*, 25, pp. 575-581.

GILLE, Bertrand (1975) : "Progrès Scientifique, Progrès Technique et Progrès Economique", *Fourth International Congress of Economic History, Bloomington 1968*, Paris, Mouton, pp. 209-222.

GILLESPIE, Charles (1957): "The Discovery of the Leblanc Process", *Isis*, 48(2), June, pp. 152-170.

—(1957a): "The Natural History of Industry", *Isis*, 48 (4), December, pp. 398-407.

—(1965): "Science and Technology" in CRAWLEY, C. W. (ed.), *War and Peace in an Age of Upheaval 1793-1830. The Cambridge Modern History*, Vol. IX, Cambridge University Press, pp. 118-145.

—(1983): "The Flourishing of French Science", second part of the Author's *The Professionalization of Science: France 1770-1830 compared to the United States 1910-1970*, Kyoto, Doshisha University Press, pp. 21-40.

HAHN, Roger (1975): "Scientific Research as an Occupation in Eighteenth Century Paris", *Minerva*, 13(4), pp. 501-513.

HALL, A. Rupert (1974): "What did the Industrial Revolution in Britain owe to Science?", in MCKENDRICK, Neil (ed.), *Historical Perspectives: studies in English thought and society in honour of J.H. Plumb*, London, Europa Publishers, pp. 129-151.

—(1983): *The Revolution in Science 1500-1750*, London, Longmans.

HANS, Nicholas (1951): *New Trends in Education in the Eighteenth Century*, London, Routledge.

HOBSBAWM, Eric J. (1962): *The Age of Revolution 1789-1848*, New York, New American Library.

HOMBURG, Ernst (1999): "The Rise of Analytical Chemistry and its Consequences for the German Chemical Profession (1780-1860)", *Ambix*, 46 part I, pp. 1-32.

INKSTER, Ian (1991): "Mental Capital: transfers of knowledge in eighteenth century", *Science and Technology in History: an approach to Industrial development*, Basing-stoke, macmillan, pp. 32-59.

JACOB, Margaret C. (1997): *Scientific Culture and the Making of the Industrial West*, New York, Oxford University Press.

LUNDGREEN, Peter (1990): "Engineering Education in Europe and the USA, 1750-1930: the rise to dominance of school culture and the engineering profession", *Annals of Science*, 47, pp. 33-75.

MCKIE, Douglas (l965): "Science and Technology" in GOODWIN, A. (ed.), *The American and the French Revolutions 1763-1793, The New Cambridge Modern History*, Vol. VIII, Cambridge University Press, pp.115-142.

MENDELSOHN, Everett (1964): "The Emergence of Science as a Profession in Nineteenth-Century Europe" in HILL, Karl (ed.), *The Management of Scientists*, Boston, Beacon Press, pp. 3-48.

MOKYR, Joel (2002): *The gifts of Athena: historical origins of the knowledge economy*, Princeton, Princeton University Press.

MUSSON, A.E. and ROBINSON, Eric (1960): "Science and Industry in the Eighteenth Century", *Economic History Review*, 13(2), December, pp. 222-244.

—(1969): *Science and Technology in the Industrial Revolution*, Manchester University Press.

O'BRIEN, Patrick (1991), "The mainsprings of technological progress in Western Europe 1750-1850" in MATHIAS, Peter and DAVIS, J.A. (eds.), *Innovation and Technology in Europe from the eighteenth century to the present day*, Oxford, Blackwell, pp. 6-17.

PORTER, Roy (1990): "The history of science and the history of society" in OLBY, Robert C. *et alii* (eds.), *Companion to the history of Modern Science*, London, Routledge, pp. 32-46.

ROSS, Sydney (1962): "Scientist: the story of a word", *Annals of Science*, 18(2), June, pp. 65-85.

SCHAFFER, Simon (1986): "Scientific Discoveries and the End of Natural Philosophy", *Social Studies of Science*, 16, pp. 387-420.

SCHECHNER, Sara (2001): "Science in the United States during the Colonial Period (to 1789)", in ROTHENBERG, Marc (ed.), *The History of Science in the United States, an Encyclopedia*, New York, Garland, pp. 494-500.

SCHOFIELD, Robert E. (1957): "The Industrial Orientation of Science in the Lunar Society of Birmingham", *Isis*, 48(4), December, pp. 408-415.
—(1959): "Josiah Wedgewood, industrial chemist", *Chymia*, 5, pp. 180-192.
—(1967): "Joseph Priestley, natural philosopher", *Ambix*, 14(1), pp. 1-15.
SLOAN, Philip R.(1990): "Natural History 1670-1802" in OLBY, R.C. *et alii* (eds.), *Companion to the History of Modern Science*, London, Routledge, pp. 295-313.
SMITH, Adam (1937 [1776]): *An Inquiry into the Nature and Causes of the Wealth o f Nations*, New York, Modern Library.
STRUIK, Dirk J. (1991): *Yankee Science in the Making: science and engineering in New England from Colonial times to the Civil War*, New York, Dover.
SZMRECSÁNYI, Tamás (2000): "Por uma História Econômica da Ciência e da Tecnologia", *Economia Aplicada* (São Paulo), 4(2), Abr/Jun, pp. 399-407.
—(2003): "Artigos sobre Ciência e Tecnologia entre a Primeira Revolução Industrial e a Segunda Guerra Mundial publicados por duas revistas de História Econômica", *Revista de História Econômica e Social* (Lisboa) nº 6, 2º semestre, pp. 125-138.
THACKRAY, Arnold (1970): "Science and Technology in the Industrial Revolution", *History of Science*, 9, pp. 76-99.
—(1974): "Natural Knowledge in Cultural Context: the Manchester Mode", *American Historical Review*, 79(3), pp. 672-709.
WENGENROTH, Ulrich (2003): "Science, Technology and Industry" in CAHAN, David (ed.), *From Natural Philosophy to the Sciences: writing the history of nineteenth-century science*, University of Chicago Press, pp. 221-253.
WILLIAMS, Raymond (1983): "Science", in the Author's *Keywords: a Vocabulary of Culture and Society*, revised edition, Oxford University Press, pp. 276-280.