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On the Historicity of the Second Industrial Revolution and the Applicability of its Concept to the Russian Economy Before 1917

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According to its title, this paper consists of two substantive parts: one reviewing some major contributions to the analysis of the Second Industrial Revolution and its essentially science-based nature; and the other dealing with the beginnings of Russia's industrialization, in order to verify how far it had advanced until 1917 with regard to the main characteristics of that process. Both of them, particularly the latter (due to my ignorance of the Russian language) will be fundamentally historiographic and exploratory.

Unlike the First Industrial Revolution, which has already originated a lot of discussions and controversies, the Second did not yet occasion the issue of a great amount of publications, and its analysis up to now only seems to be requiring a more precise conceptual framework and periodization. The times which I am here considering extend from the late 1850s, marked by the emergence of the first modern steel production processes, to the beginning of the 1930s, when electrification had been completed in the most advanced industrialized countries, and when the civilization of the automobile had already become firmly established within them. My interest in their study will be centred upon the mutual influences and relationships between scientific and technical progress on one hand, and the economic development of advanced industrial societies on the other, always taking into account the mediation of the policies specifically designed and implemented for their respective promotion.

Thus, in relation to the beginnings of Russia's industrialization, I shall not only attempt to assess the initial dates and features of its main manufacturing branches, but also seek to enquire which were the economic, scientific and technological policies put into practice to forward them, both by the State and by the private enterprises operating in that country before the 1917 Revolution. Besides being relevant in themselves, these questions present a considerable interest from the viewpoint of the spatial and temporal diffusion of the Second Industrial Revolution, which, like the First, begun earlier and evolved faster in some countries than in other, thereby giving origin to various kinds and trajectories of economic development. Russia tends to be considered a latecomer to industrialization in general and apparently did not enter the Second Industrial Revolution before the first decades of the twentieth century. This impression, however, requires a better empirical verification.

I

In a rapid glance to the last decade's literature, I was able to identify only five instances of a discussion more directly focused upon the occurrence and nature of the Second Industrial Revolution: two articles published in 1996 – one by James P. Hull and another by myself[1]; the editors'introductory chapter of an important book on *Big Business and the Wealth of Nations*, issued in the following year; the first part of a book entitled *Les Deux Révolutions Industrielles du XXe Siècle*, by François Caron, published in 1997; and the theoretical and historiographic survey of the second part of *As Time Goes By: From the Industrial Revolutions to the Information Revolution*, published by Chris Freeman and Francisco Louçã in 2001. Although not all the last ones mention each of the former, their analytical frameworks and perspectives appear to be quite similar in every case. Even so, however, there are still other authors and other works that didn't arrive to be mentioned by most of them.

Remounting in time, we may mention, for example, a posthumous booklet by H. Pasdermadjian, *La Deuxième Révolution Industrielle*, published in 1959 and probably one of the earliest works directly dealing with the subject. Its 152 pages, including a bibliography and the table of contents, display a broad view of that process, centred on its technological and organizational aspects, and emphasizing its foundations in discoveries, inventions and new knowledge. According to the Author, the outcomes of these became materialized in new sources of energy, the applications of electricity to industrial production, the emergence of increasingly complex machine-tools, and the mechanization of agriculture, while the drastic transformations that they entailed gave origin to the mass production and mass consumption patterns of our times.

It is worthwhile to stress, however, that some years earlier, at the beginning of the 1950s, although without specifically mentioning the Second Industrial Revolution, the

1 Complete references of all mentioned works can be found in the bibliography at the end of this paper.

physicist and pioneer of science policy studies J.D. Bernal had already treated in greater depth many of these same issues in his *Science and Industry in the Nineteenth Century*, and then again, a little later, in chapters 8 and 9 of his famous *Science in History*.

Much closer to the five recent studies mentioned earlier, we can find another specific and stimulating contribution in an article of 1992 by Thomas P. Hughes, who personally would have preferred to use the term “technological revolution” instead of “industrial revolution”, but did not object to the latter’s idea and concept, particularly when applied to the Second Industrial Revolution. Taking as examples the main discoveries and inventions in the fields of electricity, photography, internal combustion engines and flying machines, he examined the period that I have just defined, locating the initial occurrence of that revolution in Germany and in the United States, similarly to what had happened before with the first one, whose onset had been in Britain during the last decades of the eighteenth century.

One of the authorities mentioned by Hughes, and also figuring as such in the book by Freeman & Louçã, is the French economic historian Bertrand Gille, editor of an impressive *Histoire des Techniques: Technique et Civilisations, Technique et Sciences*, published in 1978 and translated into English eight years later. But, before turning to this analytical landmark of our subject, it may be useful to follow an earlier and more familiar track, which goes back to the emergence of David Landes’influential *Unbound Prometheus*, published as a book in 1969, but which had originally appeared three years earlier as a very long chapter of the sixth volume of the *Cambridge Economic History of Europe* edited by H.J. Habakkuk and M. Postan, a volume that had received the suggestive title of *The Industrial Revolutions and After*, thus strongly supporting the idea of the existence of a second after the first and classical one. Both this volume and specially Landes’work can be considered as having given a wider and more definite currency to the concept and existence of a second industrial revolution within the English language economic historiography.

Almost at the same time, however, Eric Hobsbawm had also arrived to a very similar perspective at the beginning of chapter 9 of his *Industry and Empire*, published in 1968. Furthermore we cannot forget that the idea of successive industrial revolutions has a still older pedigree, which goes back at least to Schumpeter’s *Business Cycles* of 1939, and before him to the mid-1920s papers of Nikolai Kondratieff. Although accepting the general notions put forward by these two authors, I prefer to work with the aforenamed concept of Second Industrial Revolution and with the periodization that I have proposed at the beginning of this paper.

Industrial revolutions, like all revolutions, are historical processes (and not events or phenomena) characterized by their amplitude, pervasiveness and irreversibility. Their occurrence usually results in or is accompanied by the emergence of new materials, new sources of energy, new productive processes and new products. All of these have been present in the Second Industrial Revolution, which also gave origin to new and definite mutual relationships between science, technology and economic development, duly mediated by the advent of adequate policies, formulated and implemented by governments and/or by the emerging multinational enterprises of the economically most advanced capitalist countries. Such processes are well documented in the already mentioned works of Bertrand Gille and by Freeman & Louçã, which are complementary to each other, and also to my own article of 1996. Bertrand Gille's contributions still remain very important to our days from a conceptual and periodization point of view, while Freeman & Louçã's book has the advantage of updating and rounding off a great amount of the available empirical information.

Bertrand Gille's essays of 1978 were preceded ten years earlier by a report presented at our Association's fourth conference (1968), in which he discussed the relationships between scientific, technical and economic progress, showing that the first one is better known than the other two because it has been more intensely studied. With regard to the second, based upon the ideas of Schumpeter and of the French economist François Perroux (1903-1987), he differentiated the concepts of invention and innovation, emphasizing that only the latter affects economic progress, equated by him to economic growth (whereas my own conceptual preference would rather tend towards the process of economic development). In accordance to this perspective, we may consider that only innovations are part of the economists' idea of technical progress, while inventions proper belong to the field of technological development, which, like that of the discoveries of scientific progress, basically refer to knowledge *per se*.

Although influenced by the evolution of the economy, both the discoveries of science and the inventions of technology possess an internal history and a specific logic of their own, and therefore are not reducible to mere derivations or consequences of economic development. And to this, we may still add that, ever since the times of the First Industrial Revolution, both have become not only self-sustaining (some thing which did not yet occur either with the innovations of technical progress or with the economies' growth and development), but also increasingly related to each other. It was precisely this growing and reciprocal interdependence between them which finally resulted in the science-based technological inventions and innovations of the Second Industrial Revolution. Such a result, of course, was not obtained immediately and spontaneously, nor did it follow automatically from the increasing complexity of industry's technological problems. It has rather been the outcome of deliberate policies formulated both by governments and enterprises, as well as of some larger ad more pervasive processes, like the nineteenth's century's gradative professionalisation of research activities within and outside the higher education establishments.

The interdependence of all these processes can be analysed either statically at a given point of time, taking into account their systematic features and their structural patterns, or dynamically through time, by inserting the changes incurred by these systems and structures within some broader framework of socioeconomic evolution. The former type of analysis tends to be that of the economic theorists, while the latter configures one which has a greater historical interest. In the preface to his 1978 book, Gille stressed that technical progress can be viewed as the transition from one technical system to another, with the technical systems being taken as sets of compatible structures (or sets of relationships) envolving both technological and other variables. And also that, during the period of our interest, technical progress had occurred mainly through the incorporation of science-based inventions by current productive activities.

These same observations were again taken up by him in the first essay of that book (Gille 1978a), where he emphasized the need to assess the degree of convergence between science and technique on one hand, and the general level of a given population's scientific knowledge and information on the other, since, even without adopting any chronological determinism, one can perceive that some inventions can only emerge at a given time and within quite specific circumstances (Op. cit., p. 38). But, for our purposes, the most interesting part of his book is represented by an intermediate essay (Gille 1978b), in which he establishes and justifies a periodization similar to that of my 1996 article, which, unfortunately, had been written without the benefit of his authoritative support. According to Gille (as to myself), the Second Industrial Revolution has taken place during the second half of the nineteenth century and the first three decades of the twentieth (Op, cit., pp. 773, 797 and 843-844). Another merit of his work relates to the fact of calling attention to the concomitant changes that were taking place in the most developed economies both at their national and international levels. These transformations were represented respectively by a growing concentration of output in all industries and markets, as well as by an increasing size of their bigger enterprises, and by the imperialist expansion of European and North American industrial capitalism to Africa, Asia, Oceania and Latin America (Idem, pp. 775-6).

It is always important to remind that economic growth is not necessarily accompanied by technical progress, and that, on many occasions, exactly the opposite tends to occur. In an expanding economy, all producers may increase their output and sales, independently of their respective efficiency and competitiveness; the growth of the demand and prices of all goods and services helps to conceal their differences in costs and productivity. Despite of this, and similarly to what had happened before at the times of the First Industrial Revolution in Britain, the third quarter and later on the last years of the nineteenth century together with the first decade of the twentieth have been, both in Western Europe and in the United States, periods not only of intense economic growth and development, but also of widespread technical progress, with the latter being largely induced by the former[2]. And this was fundamentally due to an increasing industrial competition caused by the widening of the markets for all goods and services from their local and regional origins, first to a national level, and thence to the international and global ones, by the way of ever faster and cheaper means of transport and communications.

This general progress was not immune to occasional overproduction crises, like that of 1857, or even to more prolonged recessions, such as the so-called Great Depression, which lasted from the early 1870s to the mid-1890s, or that of the twentieth century ‘s interwar period. These phenomena led to several attempts of controlling and restraining intercapitalist competition through cartels, trusts and other oligopolistic agreements or arrangements, which however generally did not succeed to last for long time and, more importantly, were unable to eliminate competition as such, only contributing to shift its scope and nature from an exclusive reliance on pricing to the use of and appeal to other variables, particularly to technical and organization innovations. And it was precisely the persistence and consolidation of these new forms of competition which determined and conditioned the onset and diffusion of the Second Industrial Revolution, everywhere promoted by the appearance and expansion of some larger, pioneering, dynamic and innovative enterprises, aptly defined as “first movers” by Alfred Chandler’s important synthesis of 1990.

According to this author, “it was their investments in the new and improved processes of production, more than the innovations themselves” that initially lowered their costs and increased both their productivity levels and market shares. Or, in his own words:

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[2] The last of these periods (from the mid 1890s to the First World War), which became internationally known as the *belle époque*, has been considered by François Caron the beginnings of the Second Industrial Revolution, whose effects, according to him, endured until the first half of the 1970s.

> "It was the investment, not the innovation, that transformed the structure of industries and affected the performance of national economies. It was investment that created the new institution – the modern industrial enterprise – and it was investment that built the specific enterprises in the new or reshaped industries in which further, cummulative innovation in product and process would come. It was investment, not innovation, that determined entrepreneurial success or failure in the new industries of the Second Industrial Revolution". (Chandler 1990, p. 63).

At the end of the nineteenth century, several of these enterprises were already quite large and even becoming some of the biggest multinational firms of our own days. The oligopolistic competition prevailing among them was at that time, and continues to be nowadays, qualitatively different from the "free" competition that had existed in previous decades among a greater number of smaller and medium-sized concerns. Through the intensification of competition, the smaller and weaker competitors tend to be driven out of business and all industries, one after the other, tend to become ever more concentrated into a smaller number of bigger and stronger enterprises up to the point at which none of these remains capable to eliminate the others of similar size and strength.

During the second half of the nineteenth century, this concentration was occurring more conspicuously among the "heavy" industries manufacturing production goods (intermediate raw materials, capital equipment) than in the "light" and traditional consumer goods industries like textiles. It was precisely within the former that the Second Industrial Revolution initially took place, and from there later expanding to all others, beginning by those of the durable consumer goods (transportation vehicles, domestic appliances etc.). And in none of them was any enterprise able to aspire or to attain a monopolistic position, something which was less due to legal or administrative impediments than to basically technological reasons, since due to the inbuilt and self-sustaining innovation processes it had always become possible to substitute scarce and/or expesive goods by cheaper and more abundant ones.

Particularly in the USA, but also elsewhere (for instance in Germany), that was the time at which emerged many of the now existing larger oligopolistic enterprises – enterprises that are horizontally concentrated with regard to their output, and vertically integrated with regard to their inputs, thus controlling the production and prices of most industries in all economies, big or small, central or peripheric, developed and underdeveloped. Besides being essentially multinational, these enterprises are nowadays creating and developing inhouse most of their technological resources, a trend that had appeared already at the end to the nineteenth century and at the beginning of the twentieth, due to and by way of the Second Industrial Revolution. And these processes coincided in time not only with the aforenamed transition from “free” to oligopolistic competition, but also with the onset, growth and heyday of advanced capitalism’s imperialistic expansion, whose occurrence was made possible by the economic and military superiority of the Western European and North American developed countries.

The origins of that superiority can be traced back to the times of the First Industrial Revolution. Despite of having been entirely normal and understandable within a material perspective, the underlying process which led to it can be considered surprising and contradictory trend in relation to the decolonization process which was occuring since the previous century with the independence of the USA and the disappearance of the Iberic colonial empires in South and Central America, and *vis-à-vis* the shrinking of other ones, like the French and the Dutch. But, as a matter of fact and notwithstanding the just mentioned events and trends, the territorial share of European countries’metropolitan and colonial areas rose from 55 per cent of the Earth’s total at the beginning of the nineteenth century to 67 per cent around 1875, and to 84 per cent on the eve of the First World War (Fieldhouse 1982, p. 178). And it is important to stress that the main objectives of that expansion were economic, namely: (a) the access to exclusive and/or protected markets for goods and services; (b) the access to strategic and/or low cost raw materials; and (c) the obtention and promotion of new opportunities for investing idle and redundant capital resources.

This substitution of the old mercantilist colonial empires by nineteenth century’s imperialism, which in several regions of the globe lasted until after the Second World War, has been analysed and explained by many authors – from J. A. Hobson and Rudolf Hilferding, through Rosa Luxenburg, Lenin and Bukharin, to D. K. Fieldhouse (1982) and Eric Hobsbawm (1987), whose various arguments will not be assessed here. It is sufficient for our purposes to mention that this imperialism and its mechanisms of domination gave origin to new phenomena and trends which changed the face of the world and still continue to reverberate until our days. There are no doubts that the world in which we now live is very different from that of one hundred years ago, at the beginning of the twentieth century; but it still remains true that the latter was even more diverse from the one which had existed one hundred years earlier, at the beginning of the nineteenth century.

At the turn of that century to the twentieth, most of the world was already well known, at least in geographical terms, something that hadn’t been the case at the beginning of the nineteenth, when huge areas of Africa, Asia, Latin America and Oceania still remained unmapped, and when several journeys still required weeks, or even months, to be completed. This was surely not the prevalent situation one hundred years ago, when telecommunications had already been sufficiently well developed for the circulation of any information in a matter of days or hours, no more requiring the dislocation of persons and/or writings, and when the means of transportation on land and sea had already become fairly rapid. And above all, the world at the beginning of the twentieth century could already be perceived, like ours today, as divided between centre(s) and periphery(ies), between advanced and backward societies, developed and underdeveloped economies, etc.

These were (and are) differences that had not existed before the First Industrial Revolution, and which certainly became further magnified by he occurrence of the Second, together with the imperialistic expansion of advanced capitalism which accompanied it. Such differences, like those of the present, were not only quantitative, but also involved important qualitative aspects at the cultural and institutional levels, including those which specifically refer to science and technology.

Contrarily to most other authors commented so far, Chris Freeman and Francisco Louçã textually declared to prefer continuing to use the Kondratiev wave classification scheme (Op. cit., pp. 145-6), instead of the First and Second Industrial Revolution concepts adopted here. Despite of this, we can jointly take and consider their chapters 7 (“The Third Kondratiev Wave: the Age of Steel, Heavy Engineering and Electrification”) and 8 (“The Fourth Kondratiev Wave: the Great Depression and the Age of Oil, Automobiles, Motorization, and Mass Production”) as a proxy to our dealing with the Second Industrial Revolution, Furthermore we need to point out that these two chapters, comprising pages 220 to 300 of the aforenamed book, were preceded by the quite similar and convergent first part of another book previously issued by one of the authors and entitled “The Rise of Science-Related Technology”, in the third edition of *The Economics of Industrial Innovation*, published in 1997 by Chris Freeman and Luc Soete.

Although this older book didn’t mention yet the occurrence of a second industrial revolution, its chapters 3 (“The Age of Electricity and Steel”), 4 (“Process Innovations in Oil and Chemicals”) and 6 (“Mass Production and the Automobile”) can be taken as initial versions of the 2001 work’s two chapters mentioned in the previous paragraph, either for presenting *ipsis litteris* parts of its contents, or by being highly complementary to it. This complementarity can also be partly extended to chapter 16 of the 1997 Freeman & Soete book, on the “Aspects of Public Policy for Science, Technology and Innovation”. It applies only in part because most of its contents refers to more recent developments, and not specifically to the period of our interest, while Freeman & Louçã's book only presents a few isolated and marginal comments on these issues, thus inducing us to seek elsewhere the required informations about them.

But, leaving aside this limitation, there can be no doubt that the analyses contained in these two books are extremely useful for our purposes. The starting point of both resides in a differentiation between the origins, the development and the characteristics of the major and most successful innovations of the eighteenth century's First Industrial Revolution in Britain, and those of the late nineteenth century and early twentieth in the United States and Germany (Freeman & Soete, pp. 55-58). And equally valuable is their reminder that "the new wave of technical advance and structural change from the 1870s onward was driven not only by a new constellation of inventions and innovations, but also by the declining profitability, intensified competition and diminishing opportunities for new profitable investment in the now mature older industrial sectors…" (Freeman & Louçã, p. 214).

The huge increase of Germany's and the United States'steel production from the early 1880s to the eve of he First World War has been attributed by these authors to the radical manufacturing process innovations that had been made and diffused throughout the previous three decades, resulting in a tremendous fall of costs and prices, and were responsible for the constant and intense widening and diversification of its consuming markets (Idem, pp. 233-8). And they also stressed that all the inventors of these new processes were formally trained engineers or chemists who did put in practice what they had previously learned and acquired through their scientific or technical education. The same occurred with most of their adopters and diffusers who were also either equally versed in most of their underlying concepts and methods, or at least capable to enroll and hire the services of scientifically and technically competent personnel. This was something that had only seldom occurred during the First Industrial Revolution, whose technologies were usually much simpler, more familiar and traditional, tending to be well known by most people involved in their respective trades.

Such features proved to be, of course, even more conspicuous in the case of electricity, whose industrial utilization was clearly "more science-related than either textiles or steam engines" (Op. cit., p. 222), and for whose development "the role of laboratory-science….was much more obvious and direct than in the case of mechanical techniques" (Freeman & Soete, p. 64). In this case as well the relevant new technologies took a long time to mature and to be transformed into successful products in economic terms. And all of them were also based upon scientific discoveries and technological inventions. Nonetheless it is important to remind once more in this respect that the relationships between science and technology on the one hand and industry on the other were neither linear nor one-directional, with their complex and multilateral nature having been well illustrated by an 1996 article of Wolfgang König[3].

Anyhow it remains true that most of electricity's properties were already fairly well-known in scientific terms at the beginning of the nineteenth century, and that, during various decades, its main applications were largely confined to telecommunications. It was only during the 1850s and 1860s that the development of magnetos and dynamos finally led to the beginnings of electricity's use in illumination, and at least other two decades were needed to put in place the large scale electric power generation and transmission systems, as well as the suitable lamps by which its producers could at last find their first markets in domestic household lighting and in local public illumination. This market was soon followed and completed by that of urban public transportation, but the most revolutionary aspects of electricity in economic terms appeared still later, with the electrification of all industrial production and of most public and private services, a development only made possible by the large scale generation and transmission of electric power.[4]

Finally having been transformed into a universally producible commodity, electrical power's industrial uses (in motors and furnaces) and applications (in electrometallurgy and electrochemistry) allowed the appearance of numerous new materials, new productive processes, new intermediate and final products, and simultaneously gave origin to a general increase of economic productivity and to an at least potential general improvement of social living standards. None of these development would have been attained so rapidly without the intensification of technological research by the industry's enterprises (Freeman & Soete, p. 84; Freeman & Louçã, p. 226). Both their amplitude and pervasiveness can be assessed from the following quotations:

> "In some countries the sate and municipalities played a much greater role than private firms in the development of the (electrical) industry.
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> …Whatever the particular national and local institutional framework, the growth of the new electricity infrastructure required a new regulatory

[3] Wolfgang König, "Science-Based Industry or Industry-Based Science: Electrical Engineering in Germany before World War I", *Technology & Culture*, 37 (1), Jan. 1996, pp. 70-101.

[4] The process synthesized in this paragraph has also been well discussed in chapter 2 of François Caron's book, entitled "*Du charbon-roi aux nouvelles technologies*" (Op. cit., pp. 79-149).

> framework, new legislation, new standards, and massive private and public investment" (Freeman & Louçã, p. 229).
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> "The full expansionary benefits of eletric power on the economy depended…not only on a few key innovations in the 1880s, but on the development of a new "paradigm", "style", or production and design philosophy… (This) change of paradigm was comparable to the present change of paradigm based on the Internet and information technology, or to (that of) the earlier mechanization of industry based on steam power" (idem, pp. 230-1).

Christopher Freeman and his associates have also interesting things to say about the chemical and oil industries, and also on the advent, the initial characteristics and main consequences of our automobile age, as well as on motorization and mass production (and mass consumption).

According to them, the chemical industry's high rate of productivity advance was mainly due to the technical move from batch to flow processes, and to a progressive scaling up of production, which resulted in great reduction of unit costs and a considerable improvement of all chemical products'quality and uniformity (Freeman & Soete, pp. 85-6). These transformations, which had begun during the last decades of the nineteenth century, were facilitated by six major developments, namely: (1) the enormous growth of the market for basic chemicals; (2) the switch in basic materials for organic chemicals from coal derivatives to those of oil and natural gas; (3) the increasing availability of electricity as a source of energy; (4) improvements in the materials used for plant contruction and in equipment components; (5) the development of new instruments for the monitoring and control of flow processes, as well as for laboratory analysis and testing; and (6) the application of basic scientific knowledge to the development of new processes and new products" (Idem, pp. 86-7).

This last factor gave origin to the new disciplines of industrial chemistry and chemical engineering[5], while the former derived from a historical, economic and technological supremacy of the United States oil Industry. This industry, as it is well known, had been initially developed in the nineteenth century as a source of querosene for lighting, and of heavy oil for heating. Its shift to the production of mainly gasoline was determined by

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[5] See in this respect Klaus Bucholz, "*Verfahrenstechnik* (Chemical Engineering) – its Development, Present State and Structure", *Social Studies of Science*, vol. 9 (1979), pp. 33-62; and Nathan Rosenberg, "Technological Change in Chemicals: the Role of University-Industry Relations", *in* Ashish Arora *et alii* (Eds.), *Chemicals and Long Term Economic Growth* (New York: Wiley, 1998), pp. 193-230.

the development of the internal combustion engine, which finished by originating the contemporary automobile industry, and by the ever increasing demand for that product, which stemmed from the exponential growth of this industry during the first half of the first half of the twentieth century. The technical changes involved in these processes were far from instantaneous, usually requiring several decades for their completion:

> "It took a series of inventions and innovations before gasoline could be separated (through cracking) in sufficiently large quantities of good enough quality and low enough cost to provide it on the scale needed for the mass use of automobiles" (Freeman & Louçã, p. 281).

And they were also quite expensive: "All the main cracking processes developed after the First World War had cost more than one million dollars each" (Freeman & Soete, p. 98). But, thanks to these investments, the ensuing progress could be very swift: "between 1910 and 1939, production had increased so rapidly that the industry grew much faster than world industrial production. The price of oil, relative to other commodities, was falling… Its production thus satisfied the twin criteria of universal availability and descending price" (Freeman & Louçã, p. 281).

The first main inventors, innovators and entrepreneurs of the chemical industry created in the last decades of the nineteenth century were all formally trained chemists who had spent many years of their lives conducting research at their own expenses and personal risk, and all of them attached considerable importance to patents. In that capacity, they were later substituted by the in-house industrial laboratories of their firms, which in turn became important members of the twentieth century's international chemical industry (Freeman & Soete, pp. 88-9). Much the same evolution took place even faster within the world's petroleum industry. The emerging R&D departments of these industries frequently collaborated with independent inventors, university research centers and governmental institutes. Innovations by small firms did not disappear in this context, but their relative importance, mainly due to the rising costs of underlying research, tended to decline (Idem, p. 106).

Simultaneously to the productivity gains that were being obtained in the chemical and petroleum industries through the introduction of flow processes and a general scaling up of production within ever larger plants, comparable advances were also made in some other industries through the introduction and diffusion of the interchangeable parts system together with assembly line production, pioneered and developed by the expanding automobile industry (idem, p. 137). It was Henry Ford's immense success in this which obliged the

American firms of this industry either to adhere to the assembly line, or to become small niche producers, or even to leave business altogether. Some of his competitors however combined in a rival company, General Motors, which successfully challenged Ford in the 1920 and 1930s, by introducing a strategy based upon a greater range of models, more frequent model changes, and steady incremental improvements coming partly from production engineers, but also from a large and diversified R&D activity. This firm also supported basic (in-house) research on the grounds that a company's strategy needed to be geared towards long-term profitability, and not merely to short-term profit maximization (Idem, pp. 144-5).

It was the combination of mass production of automobiles and the abundant availability of cheap petroleum that made possible the twentieth century's motorization of the world economy (Freeman & Louçã, p. 281). This process included not only the conversion of most terrestrial and aquatic means of transportation, but also tractors and mechanical harvesters for agriculture, as well as aircraft, all of them having equally emerged within the Second Industrial Revolution, and been based upon innovation proceeding from technological inventions and/or scientific discoveries.

The deliberate promotion of science and technology both by enterprises and by governments has been the subject of several analyses by a number of authors, including, including Freeman & Soete (1997). But the already mentioned chapter 16 of their book, on the "Aspects of Public Policy for Science, Technology and Innovation" presents a rather scanty and casual approach to the period in which we are here interested, whose analysis is limited to a few generic propositions in its initial pages. A thorougher approach to these issues can be found in an essay review of 1994 by Jonathan Harwood[6], which discusses the new forms of scientific and technological research institutions that emerged in the most advanced industrialized countries during the last quarter of the nineteenth century and the first decades of the twentieth. This author's main interest lays in what he defined as "third-sector institutions", which were jointly organized by industry and government, but which through time have tended to become an almost exclusive responsibility of the latter. Such was the case of the German Imperial Institute of Physics and Technology (Physikalisch-Technische Reichsanstalt) created by the initiative and with the support of Werner von Siemens, and later of the growing set of institutes belonging to the Kaiser Wilhelm Gesellschaft, whose foundations generated the appearance of corresponding analogues in Britain, France and the

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[6] Jonathan Harwood, "Institutional Innovation in *fin de siècle* Germany", *British Journal for the History of Science*, 27(2), June 1994, pp. 197-211.

United States, which also increasingly contributed to shape and coordinate these countries'scientific and technological development.

In all of them, this task was considerably facilitated by growing private funding not only of research universities and specially established research institutes, but also, and perhaps mainly, by the progressive dissemination of the big science-based enterprises' in-house industrial research laboratories. These are frequently mentioned en passant by both the Freeman & Soete and the Freeman & Louçã books. But here again more complete and more systematic analyses are to be found elsewhere, in works not mentioned by them, such as Ernst Homburg's 1992 article on the emergence of these laboratories in the German dyestuffs industry[7], or Lilian Hoddeson's even earlier study on the beginnings of basic scientific research in what would later become the famous Bell Laboratories[8]. Another contribution in the same direction came from the upsurge of the technical-scientific propessional associations, whose German case has been well documented in an interesting essay by Peter Lundgreen[9].

II

Which of these characteristics of the Second Industrial Revolution, if any, could be found in Russia before the 1917 Revolution? Not many, according to the literature to which I have had access. One of the best conceptualizations of that country's economy at the indicated period seems to have been made by Maurice Dobb (1948: 34), according to whom, in the first years of the twentieth century, Russia's economic development, like its geographical position, "was intermediary between the undeveloped lands of Asia and the industrially developed regions of Western and Central Europe". At that time perhaps its economy appeared to be even closer to the level of the latter than to that of the former, thanks to an industrialization process which had been taking place there since the second half of the nineteenth century.

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7 Ernst Homburg, "The Emergence of Research Laboratories in the Dyestuffs Industry, 1870-1900", *British Journal for the History of Science*, 25(1) , March 1992, pp. 91-111.

8 Lillian Hoddeson, "The Emergence of Basic Research in the Bell Telephone System, 1875-1915", *Technology & Culture*, 22(3), July 1981, pp. 512-44.

9 Peter Lundgreen, "German Technical Associations between Science, Industry and the State, 1860-1914", *Historical Social Research/Historische Sozialforschung*, no. 13 (1980), pp. 3-15.

Despite of this, Dobb's opinion has been corroborated twenty five years later by a seemingly more favourable viewpoint expressed by Gregory Grossman (1973:489) in the following terms:

> "Between 1860 and 1913, the output of Russian industry (including manufacturing and mining, as well as factory and artisan production together) grew at an average rate of some 5 per cent, a high rate in that era to be sustained for over half a century. But population growth was remarkably fast too--approximately 1.5 per cent year. Accordingly, per capita increase in industry's input averaged about 3.5 per cent per year. Agricultural output increased at about 2 per cent annually, or only 0.5 per cent per head. And, because agriculture still had a predominant weight in overall output, the real national product (or income) grew at an annual rate of 2.5 per cent a year, or only 1 per cent per head. (This) per capita increase of the national product (was) a good deal below the corresponding estimates (ranking between 2 and 3 per cent) for Germany, the USA… and Japan during the same historical period".

And, a couple of pages ahead, the same author still added that "on the eve of the First World War, Russia had already had the benefit of several decades of industrialization and modernization…" But, "at the same time, it was not closing the gap in industrial terms between itself and the leading power of Western Europe and North America; it was still predominantly a peasant economy, and a poor one" (Grossman 1973, p. 491).

A few years earlier, another specialist, Roger Portal (1966:801-2) had made similar statements, showing that "development…throughout the Tsarist period (was) irregular and uneven, interrupted by crises". And also that "if we compare(it) with that of the great industrial powers and take into account the resources of Russia, we see that it was relatively weak". In the conclusion of his work, he went even further saying that Russia's industrial backwardness (before the First World War) was "an incontestable fact" (Idem, p. 862), and adding that "foreigners played a very important part in its industrial advance, contributing not only the capital, without which Russia's industrial development would have been much slower, but also talent" (Idem, p. 863).

This was specially true with regard to technology, as has been reminded twenty years later by Peter Gatrell (1986:159): "Russian entrepreneurs could have installed advanced Western technology under licence, but this option was not available in practice: foreign firms were too keen to exploit the protected Russian market themselves". Thus, according to

Maurice Dobb (1948:38), "nearly half of the capital invested in the Donetz coal basin prior to 1914 was foreign, and over 80 per cent of the capital in iron mining, metallurgy and the oil industry". Similar figures were arrived at by Portal (1966:851), according to whom,

> "foreign investments represented about one third of the capital invested in the existing two thousand or so companies. The proportion reached 90 per cent in mining business, more than 40 per cent in metallurgy, 50 per cent in chemical industries and 28 per cent in textiles. Out of the total (foreign) investment… French capital accounted for one third, English capital for one fourth, German for one fifth, and Belgian for 14 per cent".

Anyhow nonetheless, the fact remains that an industrialization had really taken place before the 1917 Revolution. But this process, although very rapid at some times and quite intense in some instances, did not advance much beyond the main branches and processes of the First Industrial Revolution, as will be shown in the subsequent pages of this article. Its origins remount to the 1840s, when the first modern cotton textile mills were installed in Russia, but its consolidation only began to occur two decades later, with the 1861 emancipation of the serfs, which, specially in the long run, came to facilitate the free recruitment of the necessary labour force, as well as the formation of a national market economy.

The latter, as it has already been said, was strongly conditioned by the influx of foreign capital, invested in most of the main new undertakings, and attracted on the one hand by Russia's vast territorial area and enviable natural resources base, as well as by its potential domestic demand for goods and services, provided by a large and fast growing population both at the level of the country as a whole and at that of its most important urban centers[10]; and, on the other, by the Russian state's active development policies.

These policies represented the continuation of a longer historical tradition, which goes back to the beginnings of the eighteenth century, when a part of Russia's economy and public administration had been forcibly modernized through the westernizing strategies first of Peter the Great, and later of Catherine II.[11] It was during their reigns that the Urals became

[10] Russia's population increased from 84.5 million inhabitants in 1870 to 97.7 million ten years later and around 113 million in 1887 (Portal 1966, p. 811). During the 1890s it continued to grow, from approximately 118 million to 133 million inhabitants in 1900 (Idem, p. 826). And the size of its main towns also did increase very rapidly: in 1914, St Petersburg had already more than 2 million inhabitants, being closely followed by Moscow, with its 1.8 million, whereas Riga, Kiev and Odessa had all populations of over 500 thousand inhabitants each (Idem, p. 845).

[11] See in this regard the considerations of Ian Inkster's chapter, "Technological and Industrial Change: a Comparative Essay", in Roy Porter (Ed.) *Eighteenth Century Science*, volume 4 of *The Cambridge History of Science* (Cambridge University Press, 2003), pp. 858-66.

an important area of iron mining and smelting, thus transforming the country into one of the world's largest producers and exporters of this metal, a situation which endured quite late into that century, until when it was finally overtaken by Britain during the First Industrial Revolution. To this old iron industry, based on the use of serf labour compulsorily assigned to work in its mines and factories, the 1861 emancipation "dealt a blow from which it never properly recovered" (Dobb 1948, p. 56).

Despite of this, however, during the second half of the nineteenth century, there did occur not only a revival but also a further growth of Russia's iron production. And this was due again to the stimulus of governmental policies and actions. But now it occurred "less directly than under Peter's westernizing policy, as a result of the demand created by the railway building of the 1860s and 1870s". And at that time, "instead of being in the Urals, where coal was deficient and charcoal furnaces had been used", this new iron industry "was located in the south, between the Donetz and the Dnieper, where there were plentiful sources of good coking coal…and rich iron deposits at Krivoi Rog, some 200 miles to the west" (idem, pp. 55-58).[12] Much of it furthermore "was fairly modern in type and was marked by a surprisingly high level of concentration both of production and of ownership and control" (Idem p. 34). Similar viewpoints have been expressed later by Peter Gatrell (1986:153-4 and 158).

According to Portal (1966:827-8), "a real industrial complex …developed in the Ukraine…bound up with foreign capital", to which we may add foreign technology. As he indicates,

> "The three great companies…established before 1890…were undertakings on a large scale, owning iron and coal mines, and furnished with ample financial resources, materials and staff of high quality, and in 1899 they counted 15 blast furnaces, 24 Siemens-Martin furnaces, 42 puddling furnaces and 23 rolling mills".

In turn, Peter Gatrell (1986:158-9) stated that

> "The average capacity of their blast furnaces was less than in Belgium or Germany, but the difference was offset by the higher quality iron ore used in Ukraine, which yielded more pig iron per ton of ore". Even so, the average size of these blast furnaces grew during the period 1890-1913 from between 120

[12] It should be noted, however, that Russian coal production didn't grow fast enough for the country's increasing demand. According to Portal (1966:817), it had to import 25 per cent of its coal consumption between 1886 and 1890.

> and 180 up to around 250 tons… at the same time, their "modern integrated plants used both the Bessemer and (Siemens-) Martin methods, according to the requirements of the market :the former for bulk production of basic steel, the latter for special others"…And "rolling mills were also in accord whit Western practice, though they (still) used steam when the most modern German and Belgian firms were switching to electricity".

The same author in a later work (Gatrell 1994) state that

> "By the beginnings of the twentieth century, Russia has joined the ranks of the world's major producers of iron and steel. …Foreign entrepreneurs (had) installed new Bessemer converters and Siemens-Martin open-hearth furnaces. New rolling mills, supplying steel rails, structural shapes and steel sheet represented another breakthrought." (Op. cit., p. 47)

Therefore, at least in those branches, we can perceive an adoption and use of Second Industrial Revolution technologies. But, how about the other branches of Russia's manufacturing industry? According to Grossman (1973:488), "Prior to the 1861 Emancipation of the Serfs…a few industries based on the new technologies of the time began to appear and to spread. These were chiefly consumer goods industries – textiles, sugar – aimed at internal demand, enhanced …by the rapid growth of population".

Nonetheless, according to Portal (1966:809), the growth of these industries "was hardly accompanied by the general transformation of the economy and social structure which characterizes a revolution". His opinion coincided with a previous statement of Maurice Dobb (1948:35-6), for whom "the patches of factory industry in the Leningrad (sic) and Moscow districts and in the south were no more than industrial islands in a vast agricultural sea, bordered to the north by deep forests and to the south by mountains and desert". Furthermore, still according to him, "the factories that existed were frequently foreign importations: foreign-owned, foreign-financed, and staffed by foreign managerial and technical personnel". And a large part of these industries'machinery was also imported from abroad, the same occurring with several other inputs and raw materials (Idem, pp. 36-6).

It was within this context that the Russian state's intervention came to make a difference, with the beginning of the policies directed towards the construction and expansion of the country's railroads from the mid-nineteenth century on. "The first major line, connecting Moscow to St. Petersburg was completed in 1852", and during the 1860s, the railroads'construction "passed mainly into private hands, though still heavily encouraged by the State" (Grossman, 1973, pp. 488-9). And thence on, "the length of track grew rapidly:

from 1.6 thousand km in 1860 to 10.7 thousand in 1870 and 22.9 thousand in 1890" (idem, p. 489).

This construction went on during the last decade of the nineteenth century and in the first years of the twentieth. "By 1903 there were 40 thousand miles (approximately 64 thousand km) of railroads in existence (about two thirds state operated) in the area of the Russian empire… a figure that (around) 1914 had increased (by) a further 8 thousand miles (or approximately 13 thousand km)" (Dobb, 1948, p. 35). That network included the famous Transiberian Railway, whose 4 thousand miles (or 6.5 thousand km) linked Moscow to the Pacific coast.

That huge railway construction effort "stimulated the economy generally, not only by ending the isolation of a great many regions of the Empire, but also by bringing about a sudden increase in metal production and mining" (Portal 1966, p. 801), whose development has already been discussed in previous pages of the present paper. Besides it, we cannot leave unmentioned the fact that this evolution has "led to the introduction of modern technical and organizational methods into the country, paving as well the way for a rapid rise in international trade from the 1870s on, a trade which was largely based on the export of grain (Grossman 1973, p. 489) and also of oil[13], minerals and some other raw materials.

The proceeds of these exports, together with the direct foreign investments and part of the loans provided for railway construction formed the main financial basis of Russia's industrialization. This process displayed a moderate but sustained expansion and diversification between the early 1860s and the late 1880s. During those three decades, the number of enterprises increased more than 150 per cent – from around 15 thousand to more than 38 thousand – while that of their workers grew by a little more than 50 per cent – from 860 thousand to 1.320 thousand (Portal, 1966, p. 815).

At the same time, the Russian state was tending again to take a more active role in the promotion of economic development. And this occurred not only through the initiative of undertaking and/or incentivating the construction of railroads, but also by the way of an increasing tariff protectionism from the end of the 1870s on and culminating in 1891 (Grossman 1973, p. 491). This policy, which had also become necessary for governmental budgetary reasons, was complemented during the 1890s by a "system of preferential treatment

[13] Cf. Portal (1966:817). According to this author (idem, p. 861), at the beginning of the twentieth century, Russia was producing half of the world's total oil, a condition that it henceforth was going to loose by degrees, maintaining less than twenty per cent of total output in 1913, as a result not only of the increasing supply of petroleum products by the United States, but also due to growing difficulties in the working of Russian wells.

given to domestic industry as a supplier of state needs", particularly for railroad construction and military procurement (Idem, pp. 491-2).

A more recent research by Peter Gatrell (1986) revealed that such policy measures went even further, evolving to outright subsidiation and financing of local steel rails production (Op. cit., pp. 150-1), as well as of rolling stock factories. Through them, the Russian government was able not only to reduce the country's dependence on foreign suppliers of these materials, thus protecting its trade surplus, but also to promote the beginnings of an industrialization process based on import substitution.

All these cumulative incentives paved the way for the intensification of Russia's industrial growth during the 1890s, and then again from the end of 1906 to the eve of the First World War.[14] During all those years, according to Portal (1966:824), "the Ukraine, more than any other region, benefited from the inflow of foreign capital… But Russian industry as a whole also profited (from this)". Such trends could be perceived "regionally in the Moscow and St. Petersburg areas, and sectorially in branches like the manufacture of locomotives, or through the establishment by Siemens of factories for electrical equipment" (idem, pp. 831-2). Other examples are mentioned by Alfred Chandler (1990:200 and 761) with regard to American investments in the Russian manufacturing plants of the Singer sewing machines and of International Harvester's agricultural machinery. But the importance of the expansion of the latter's market and production had been formerly discounted by Peter Gatrell (1982:102), according to whom "around one half of the total consumption of agricultural machinery was satisfied by imports", while its local "production didn't occupy a commanding role in total machine building", and its "linkages with metallurgy were not significant".

In a later work, this same author went even further stating that "In engineering and metalworking, Russia resembled Germany and Britain in the preceding generation", and that "the technologically modern plants in some branches… coexisted with plants where manual skill and power continued to dominate", whereas "efforts to introduce… mass production techniques hardly amounted to much" (Gatrell 1986, pp. 160 and 163). On the whole, this was a matter of total output's composition:

> "It was not the basic industries – such as mining and metallurgy that dominated industrial production… As late as 1913… the two broad categories of textiles and foodstuffs together accounted for half of gross industrial production… To

[14] With regard to this second and last industrialization spurt before the First World War and the 1917 Revolution, see Gatrell (1982 and 1994).

> put it bluntly, the history of industrialization in Russia was not synonymous with the growth of heavy industry" (Idem, p. 144).

At the same time however, Gatrell could not fail to notice in another work that, during the last fifteen years before the First World War,

> "The manufacture of electro-technical equipment developed with remarkable rapidity, albeit from a low base. (1994:189). Foreign direct investment played a crucial role… German capital amounted for half (of) the total investment in electrical engineering by 1913. Notable venture included subsidiaries established by AEG in 1901 (in Kharkov an Riga), by Siemens-Schuckert in 1912/12 (in St. Petersburg), and by Westinghouse in 1898 (in Moscow). …The growth in market demand was met in part by imports, especially from Germany. Total imports of electrical goods, however, grew at less than half the rate of domestic production." (Idem, p. 190).

This industrial structure was to be put on a decisive test with the advent of the First World War, which "showed up the shortcomings concealed by its brilliant façade" (Portal 1966, p. 863). In his most recent work however Peter Gatrell (2005:108) also showed that "the war enabled some branches of industry to modernize their capital stock; and it also launched newer industries such as dyestuffs, electrical engineering, and aircraft manufacture". At the same time, "in chemicals, it exposed shortage of capacity to make explosives and pharmaceuticals", for which Russia still "relied heavily on imports of raw materials". Even so, important results could be achieved in the short run: "Investment in new plant led to a rapid increase in the output of pyrites and to an improved rate of deriving benzol and toluene from coal tar", "while employment in chemicals grew from 83 thousand in 1913 to 181 thousand in 1917…" (Idem, p. 123).

These results did become possible because of the availability within the country of a fairly numerous technical personnel capable to face and to overcome these challenges. Gregory Grossman (1973:490-1) had pointed out that Russia "contained small but significant, and often high-calibre, contingents of scientists, engineers, statisticians and other qualified specialists, whose role in the future Soviet industrialization was to be crucial". The same viewpoint was upheld more recently by Peter Gatrell (2005:46-7), who showed that "the war greatly expanded employment opportunities for statisticians, accountants, engineers, agronomists, doctors…", while "in the work place the number of engineers and technical staff increased by more than one third between 1913 and 1917…" And he also emphasized that most of these professionals "were different in social origins and outlook from the (educational) products of the traditional elite institutions", having been trained in Russia's expanding polytechnic schools, which sponsored a number of specialist engineering societies". According to him, these "technical schools and universities also provided a platform for experimental work in the preparation of new drugs, vaccines, iodine and dyestuffs", while "leading scientists…carried out research in the properties of explosives, mines, gases", and "scientific and technical institutes engaged in meteorological and aeronautical research" (Idem, pp. 47-8).

For lack of space and time, we shall not be able to elaborate on the longer-run consequences of these developments, which were to be continued after the 1917 Revolution, and which have been duly focused in depth by other works particularly those of Loren Graham (1975) Robert Lewis (1979) and Alexei Kojenkov (2002). In conclusion of this part and of the paper as a whole, it may be sufficient to state that, although being a latecomer to industrialization in general, Russia at the eve of its change of regime, unlike most of the underdeveloped countries of our days, was not devoid of numerous and highly qualified scientists and engineers, whose presence and roles have been attested by the studies of various and quite diverse authors, among whom we may mention as a good recent example the paper by Irina Gouzevitch (1997) on he origins and development of Russian electrical engineering. All these analyses together with the present one serve to show that Russia, despite of not having yet actually entered the Second Industrial Revolution, possessed already before the 1917 Revolution many, if not most, of the necessary conditions for developing its relevant industries and technologies within a short period of time. And this really did happen during the intermediate decades of the twentieth century.

MAIN BIBLIOGRAPHICAL REFERENCES

Bernal, J.D. (1953) *Science and Industry in the Ninetenth Century* (London: Routledge & Kegan Paul);

Bernal, J.D. (1954, 1965, 1969) *The Scientific and Industrial Revolution*, vol. 2 of *Science in History* (Harmndsworth: Penguin Books) reprint of the third edition, pp. 365-689;

Caron, François (1998) *Les Deux Révolutions Industrielles du XXe Siècle* (Paris: Albin Michel, 1997);

Chandler, Alfred D., Jr. (1990) *Scale and Scope: the Dynamics of Industrial Capitalism* (Cambridge, Mass.: Harvard University Press);

Chandler, A.D. *et alii*, Eds. (1997) *Big Business and the Wealth of Nations* (Cambridge University Press);

Dobb, Maurice (1948) "Russian Economic Development prior to the First Word War", chapter 2 of *Soviet Economic Development since 1917* (New York: International Publishers) pp. 34-60;

Fieldhouse, D.K. (1982) *The Colonial Empires: a Comparative Study from the Eighteenth Century* (London: Macmillan);

Freeman C. & Louçã F. (2001) *As Time Goes By: from the Industrial Revolutions to the Information Revolution* (Oxford University Press);

Freeman C. & Soete L. (1997) *The Economics of Industrial Innovation*, third edition (Cambridge: MIT Press) (2000 reprint by Continuum);

Gatrell, Peter (1982) "Industrial Expansion in Tsarist Russia, 1908-14", *Economic History Review*, XXXV (1), February, pp. 99-110;

Gatrell, Peter (1986) *The Tsarist Economy 1850-1917* (London: B.T. Batsford);

Gatrell, Peter (1994), *Government, Industry and Rearmament in Russia, 1900-1914: the last argument of tsarism* (Cambridge University Press, 1994);

Gatrell, Peter (2005) *Russia's First World War: a Social and Economic History* (Harlow: Pearson);

Gille, Bertrand (1973) "Progrès Scientifique, Progrès Tecnique et Progrès Economique", *Fourth International Congress of Economic History, Bloomington 1968* (Paris: Mouton), pp. 209-22;

Gille, Bertrand (1978) *Histoire des Techniques: Technique et Civilisations, Technique et Sciences* (Paris: Gallimard); vol. 41 of the *Encyclopédie de La Pléiade*;

Gille, Bertrand (1978a) "Prolegomènes à une histoire des techniques", *Histoire des Techniques*, pp. 1-118;

Gille, Bertrand (1978b) "Les Techniques de l'époque moderne", *Histoire des Techniques*, pp. 772-858;

Gouzevith, Irina (1997) "La mise en place de l'enseignement électrotechnique en Russie (1832-1900)", *in* Laurence Badel (Org.), *La Naissance de l'Ingénieur-Électricien: Origines et Développement des Formations Électrotechniques* (Paris: AHEF/PUF), pp. 341-379;

Graham, L.R. (1975), "The Formation of Soviet Research Institutes: a Combination of Revolutionary Innovation and International Borrowing", *Social Studies of Science*, 5(1975), pp. 23-30;

Grossman, Gregory (1973), “The Industrialization of Russia and the Soviet Union”, ch. 8 of C.M. Cipolla (Ed.), *The Emergence of Industrial Societies, Part Two*, vol. 4(2) of *The Fontana Economic History of Europe* (Glasgow: Fontana/Collins), pp. 486-531;

Hobsbawm, E.J. (1968) *Industry and Empire* (Harmondsworth: Penguin Books);

Hobsbawm, E.J. (1987) *The Age of Empire 1875-1914* (London: Weidenfeld & Nicolson);

Hughes, T.P. (1992) “The Dynamics of Technological Change: Salients, Critical Problems and Industrial Revolutions”, *in* Giovanni Dosi *et alii* (Eds.), *Technology and Enterprise in a Historical Perspective* (Oxford University Press), pp. 97-118;

Hull, J.P. (1996) “From Rostow to Chandler to You: How Revolutionary was the Second Industrial Revolution?”, *Journal of European Economic History*, 25 (1) Spring, pp. 191-208;

Kojenikov, Alexei (2002) “The Great War, the Russian Civil War, and the Introduction of Big Science”, *Science in Context*, 15(2), pp. 239-275;

Kondratieff, N.D. (1935) “The Long Waves in Economic Life”, *Review of Economic Statistics*, XVII(6), November, pp. 205-15; originally published in 1926;

Kondratieff, N.D. (1979) “The Long Waves in Economic Life” (complete version), *Review*, II(4) Spring, pp. 519-562;

Kontratiev, N.D. (1998) “Long Cycles of Economic Conjuncture (1926)”, in *The Works of Nikolai D. Kondratiev*, vol. I (London: Pickering & Chatto), pp. 25-63;

Landes, David (1966) “Technological Change and Development in Western Europe, 1750-1914”, ch. V of H.J. Habakkuk & R.M. Postan (Eds.), *The Industrial Revolutions and After: Incomes, Population and Technological Change*, vol. VI (1) of *The Cambridge Economic History of Europe* (Cambridge University Press), pp. 274-601;

Landes, David (1969) *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present* (Cambridge University Press);

Lewis, Robert (1979) “The Tsarist Legacy”, ch. 1 of *Science and Industrialization in the USSR: Industrial Research and Development, 1917-1940* (London: Macmillan), pp. 1-5 and 171-2;

Pasdermadjian, H. (1959) *La Deuxième Révolution Industrielle* (Paris: Presses Universitaires de France);

Portal, Roger (1966) “The Industrialization of Russia”, ch. IX of H.J. Habakkuk & M. Postan (Eds.), *The Industrial Revolutions and After: Incomes, Population and Technological Change*, vol. VI(2) of *The Cambridge Economic History of Europe* (Cambridge University Press), pp. 801-872;

Schumpeter, J.A. (1939) *Business Cycles: Theoretical, Historical and Statistical Analysis of the Capitalist Process* (McGraw Hill);

Szmrecsányi, Tamás (1996) "Pour une Histoire Economique des Sciences et des Techniques: (3) Nature et Développement de la Deuxième Révolution Industrielle", *Sciences de la Société* no. 39, Octobre, pp. 177-193.