From Rostow to Chandler to you: How Revolutionary was the Second Industrial Revolution?

James P. Hull
University of Toronto, Canada
Okanaga University College, Kelowna, B.C.

The Second Industrial Revolution as an historiographic problem

In a 1981 essay, Peter Temin took note of what he perceived as drift in recent economic history scholarship and offered suggestions for a reanchoring of the discipline. Chief among them was a focus on the second industrial revolution as a «particular problem».[1] This excellent suggestion has, unfortunately, not been followed up and the second industrial revolution remains both an historical and historiographic problem. This lacuna is much to be regretted since a clear elucidation of the second industrial revolution could hardly fail to shed light, if only comparatively, on what is almost certainly European economic history's central phenomenon, the (first) industrial revolution. If the second industrial revolution represented a truly new departure, another stage of economic growth, then we could, as Temin implies, discover just how much blood we could squeeze out of Rostow's stone.[2] Equally, the most important new approach in the cognate field of business history, that of Alfred Chandler, might not unreasonably be summarized as a description of how second industrial revolution firms internalized transaction costs.[3]

Whence came the second industrial revolution? If, as it surely must have, stemmed from the first, then this leads us at once from the murky pool of second industrial revolution historiography into the churning seas of the first's. There one may discover virtually any shade of opinion on the role of science and technology in industrial change, presumably the key question for understanding any link to the rise of science-based technology in a later industrial revolution.

[1] P. Temin, «The Future of the New Economic History», *Journal of Interdisciplinary History*, (Autumn 1981).
[2] W.W.Rostow, *The Stages of Economic Growth*, (Cambridge, 1960).
[3] Alfred D. Chandler, Jr. *Scale and Scope*), (Cambridge, 1990).

We can have proto-industrialization without technology.[4] Conversely, we can have an industrial revolution taking effect very late and with little contribution from technology.[5] Science can have been near the centre[6] or off at the margin[7]. Clearly, this is no help at all, though enormously entertaining; we must paddle quickly back towards shore and re-enter the brackish shallows of the second industrial revolution's own «debates», such as they are.

Astonishingly, Professor Temin, like many other writers, does not choose even to define the second industrial revolution. Others typically devote a sentence or two to this task.

The term was probably coined by Patrick Geddes in his 1915 *Cities in Evolution*. Of rather more relevance, many recent authors, when they wish to cite an authority for the concept of a second industrial revolution, use Landes' justly well-regarded *Unbound Prometheus*.[8] Near the start of that work, Landes defines the second industrial revolution as «the rise of new industries based on spectacular advances in chemical and electrical science and on a new, mobile source of power - the internal combustion engine»[9].

Later he adds «precision manufacture and assembly-line production»[10]. The revolution's temporal bounds are given as being from the late nineteenth century to the Great Depression of the 1930s. If we can call anything the standard, or received, version of the second industrial revolution, this must be it.

Some scholars simply take Landes' definition, such as it is, as a given. In an essay on «The Growing Role of Science in the Innovation Process»[11] (the title could also be a short definition), Rosenberg indeed defines the second industrial revolution as new chemical technologies, electrical industries, the internal-combustion engine, precision manufacture and the assembly line, in that order.

Howard Gospel has recently taken us a bit further along the way to seeing how revolutionary the second industrial revolution was beyond the bare bones of new technology. He notes four trends in late nineteenth and early twentieth century industry:

1) New, big enterprises with activities coordinated by managers and technical staff;

[4] Myron Gutmann, *Towards the Modern Economy*, (Philadelphia, 1988).

[5] N.F.R. Crofts and C.K. Harley, «Output Growth and the British Industrial Revolution», *Economic History Review*, (November, 1992).

[6] A.E. Musson and Eric Robinson, *Science and Technology in the Industrial Revolution*, (Toronto, 1969).

[7] John Harris, *Essays in Industry and Technology in the Eighteenth Century*, (Hampshire, 1992).

[8] David S. Landes, *The Unbound Prometheus*, (Cambridge, 1969).

[9] *Ibid*, p. 4.

[10] *Ibid*, p. 235.

2) From rule-of-thumb to science-based innovation;
3) Changes in the labour force, deskilling and reskilling;
4) New ways to acquire and train staff with appropriate skills[12].

Although he is very cautious about the term second industrial revolution, it is Hobsbaum who, next to Landes, has done the most to develop the concept. His description of a later nineteenth century possible second industrial revoloution rounds up all the possible suspects: science-based technology, electricity, chemistry, internal combustion engine, mass production, Taylorism, automation, process control, continuous process technology, rising incomes to put middle class material lifestyle in the hands of large number of workers, the rise of big business.[13] That surely is revolutionary enough for anyone!

Other definitions have not challenged the above so much as added or emphasized certain factors, either economic or technological. The former includes explanations of how the new technologies favoured large, Chandlerian, firms, cartels and oligopoly[14] and led to decline in average costs across a broad front.[15] Chandler himself, shades of Rostow, has pressed the importance of investments over new technologies[16]. Additional technological factors have included steel, new alloys, synthetics, increased use of petroleum, iron steamships, the telegraph and aeronautics[17]; «advanced mechanical constructions»[18] refrigeration, new metallic mineral mining techniques, optical and glass breakthroughs and improved railway and ship construction[19], and precision instruments[20].

When did the second industrial revolution take place? Even those who have made rather a great deal out of the second industrial revolution have been rather vague about when it happened. This is remarkable as we should expect a close attention to periodization would carry with it an understanding of how the topic is to be defined.

It is broadly agreed that the second industrial revolution is synonymous with, and thus must be coeval with, the rise of science-based industry. This

[11] N. Rosenberg, «The Growing Role of Science in the Innovation Process», in Carl Gustaf Bernhard et al. (Ed.), *Science, Technology and Society in the Time of Alfred Nobel*, (Oxford, 1982), pp. 231-246.

[12] Howard F. Gospel (ed), *Industrial Training and Technological Innovation*, (London, 1991) pp. 4-5.

[13] E.J. Hobsbaum, *Industry and Empire*, (London, 1968), pp. 144-149.

[14] J. Mokyr, *The Lever of Riches*, (New York, 1990), p. 268.

[15] J. Mokyr, *Twenty-Five Centuries of Technological Change*, (Chur, 1990), p. 77.

[16] Chandler, *Scale and Scope*, p. 63.

[17] M. Kranzberg, «The Industrialization of Western Society: 1860-1914», in Bernhard et al. *Science, Technology and Society*, pp. 209-230.

[18] R.R. Locke, *The End of the Practical Man*, (Greenwich, 1984), p. 13.

[19] D. Cahan, *An Institute for an Empire*, (Cambridge, 1989), p. 14.

[20] M.J. Cattermole and A.F. Wolfe, *Horace Darwin's Shop*, (Bristol & Boston, 1987), p.v..

then marks the second industrial revolution off from the first, from which it must be distinguished as something more than a later stage.[21] The second industrial revolution commenced, in this view, when rule-of-thumb gave way to a *necessary* understanding of scientific principles underlying technology, the adoption of scientific methodology by engineers and the incorporation of new science into new technology.[22] The boldest claims perceive these changes as having commenced even as Britain's industrial revolution climaxed in the 1840s, though the changes themselves were noticed first in the German lands.[23] Others at least have the decency to wait until the Crystal Palace is up[24] or rather more vaguely write of a time «around the middle of the century»[25] when academic science comes decisively to influence industrial technology. More conservative datings only commence the second industrial revolution in the 1860s or simply «the last decades of the nineteenth century»[26].

Temin himself puts the second industrial revolution, rather vaguely, in the late nineteenth and early twentieth century, certainly a safe position. At least by implication, however, he does something far more interesting and seems to make it contemporaneous with the Progressive Era.[27] This is indeed a pregnant periodization, though one fraught with obvious difficulties for European economic history.

Even allowing a generously early date for the start of Progressivism, this puts Temin in company with other late-start advocates. These writers will allow some glimmerings of a second industrial revolution in the 1860s and 1870s, but would wait another twenty years before the revolution is fully developed.[28]

The end of the second industrial revolution has attracted no greater a consensus. Views range from the First World War[29] to the start of the Cold War[30], both of which seem unrealistic. Locke certainly has made a very

[21] Mokyr, *Lever of Riches*, p.268.

[22] Kranzberg, «Industrialization».

[23] Terry Shinn, «From 'Corps' to 'Profession'» in Robert Fox and George Weisz (ed.), *The Organization of Science and Technology in France 1808-1914*, (Cambridge, 1980), pp.183-208.

[24] Mokyr, *Twenty-Five Centuries*, p.76.

[25] M. Sanderson, *The Universities and British Industries 1850-1970*, (London, 1972),p.11.

[26] George Meyer-Thurow, «The Industrialization of Invention: A Case Study From the German Chemical Industry», *Isis*, (1982).

[27] Temin, «New Economic History».

[28] Cahan, Institute, p.14. Meyer-Thurow, «Industrialization of Invention»

[29] Cattermole and Wolfe, *Horace Darwin's Shop*,p.v..

[30] This seems to be implied by the periodization in Chandler, *Scale and Scope*. See also the argument in James W.Cortada, *Before the Computer*, (Princeton, 1993) p.95.

convincing argument for including the period between the World Wars in the second industrial revolution, insisting indeed that only then did second industrial revolution industries surpass first industrial revolution ones in importance.[31] Remarkably enough, few writers cite the First World War as being of great importance to their arguments, though surely it affected the timing of some trends in some sectors in some countries.

Another way of beginning the periodization of our revolution is to inquire into its origins. Here we discover greater, if not complete, agreement. As the textile mills of the North of English had a special role to play in the Industrial Revolution, that place was occupied, for many if not most scholars, in the second industrial revolution, by the German aniline dye industry. Agfa, Baer, Hoechst and most especially BASF were the parents of the second industrial revolution, with perhaps the *Technische Hochschulen* as godparents. In these firms, better trained foremen began replacing the traditional *Meister* in charge of production at the dye plants in the 1860s. By the mid-1870s academic chemists were being taken on and by the mid-1880s the most progressive firms had completed the process.[32] The details of this chronology however are open to dispute on a number of grounds. If first stirrings are not so important as substantive impact, then science did not become closely coupled to the dyestuffs industry in Germany until the 1880s.[33] Baudet stretches the initial revolution out to the period 1866-1895 and would see it as a more broadly-based phenomenon, within which analine dyes certainly have a special place.[34] Others are quick to assert that the United States equally with Germany is the birthplace of the second industrial revolution.[35] Both Chandler and Hobsbaum direct our attention to the very great significance of railway network-building as being part and parcel of the second industrial revolution's origins. The construction of the transcontinental lines in the United States is of especial import to Chandler's argument[36], while for Hobsbaum the railways allow us to link first and second industrial revolutions.[37] Other writers have placed stress on the change from the empirical to the academic in another sector, mining, and have implicitly or explicitly deprecated the exclusively German (or German and

[31] Locke, *Practical Man*, p.19.

[32] John Joseph Beer, «The Emergence of the German Dye Industry to 1925», Ph.D. dissertation, Illinois, 1956, pp.120-124.

[33] Meyer-Thurow, «Industrialization of Invention».

[34] Jean C. Baudet, «The Training of Engineers in Belgium, 1830-1940» in Robert Fox and Anna Guagnini, *Education, Technology and Industrial Performance in Europe 1850-1939*, (Cambridge, 1993), pp.93-114.

[35] Locke, *Practical Man*, p.3.

[36] Chandler, *Scale and Scope*, p.62.

[37] Hobsbaum, *Industry and Empire*, p.89.

U.S.) origins of the second industrial revolution.[38] Both suggestions seem ripe for the type of prolonged econometric and methodological wrangling which have come to typify the historiography of the industrial revolution itself. Certainly, we will wish to inquire into the degree to which the second industrial revolution was a unitary phenomenon and the degree to which it displayed unique national characteristics.[39]

The reader might fairly ask, at this point, what are the present writer's views on these matters? The approach which seems most useful to me in defining the second industrial revolution is to compare it, in broad-brush form, with the first. This is done in the following table. Such a comparison, of course carries with it the implicit argument that the second industrial revolution was indeed thoroughly revolutionary. It allows me as well, now, to turn from historiography to the second industrial revolution's place in history.

The first and second industrial revolution compared

First Industrial Revolution		Second Industrial Revolution
underway by last quarter of the XVIIIthC, climaxed by mid-19thC	TIME	1860s-1930s
led by U.K.	PLACE	led by Germany & U.S.
steam engines and textile equipment	TECHNOLOGY	chemical industries, electrification, internal combustion engine
factory system	INDUSTRIAL ORGANIZATION	new corporations
new working class, industrial capitalism	SOCIETY	rise of the middle-class
division of labour, skill hierarchies	WORK ORGANIZATION	Taylorism, continuous process, semi-skilled
iron and steel	MATERIALS	alloys, synthetics
laissez faire, repression	ROLE OF THE STATE	regulation, education

[38] Nicole Caulier-Mathy, «Le patronat et le progrès technique dans les charbonnages liégeois (1800-1914)» in G. Kurganvan Hentenryk and J. Stengers, *L'Innovation Technologique*, (Brussels, 1986), pp.41-62. Harry W. Paul, «Apollo Courts the Vulcans», in Fox and Weisz, *Organization*, pp.155-182.

[39] John A. Davis, «Innovation in an Industrial Late-comer: Italy in the Nineteenth Century», in Peter Mathias and John A. Davis, *Innovation and Technology in Europe*, (Oxford, 1991), pp.83-106.

If the second industrial revolution was fundamentally the rise of science-based production, it is this to which we must first turn our attention. And if it was truly revolutionary we must not end our analysis before we have addressed its social effects. Linking the two, but, curiously, ignored in almost all discussions of the second industrial revolution, is the role of the state, especially in its provision of educational services.

Science-Based Production

During the second industrial revolution, the relationship between scientific knowledge and industrial technology changed profoundly. Indeed it would not be too much to say that the whole structure of technical knowledge relating to production became reshaped over the course of that revolution. Few industries could be said to be absolutely new, springing to life fully formed like crocodiles spontaneously generated from the mud of the Nile. But most did break loose from pre-existing knowledge bases, in some cases making irrelevant bodies of knowledge which had undergone evolutionary change over a very long time. Previously unalike industries found that their productive processes in fact shared much in common now, chemical and engineering knowledge which the new managers of production had learned in new institutions of higher education.

It is not necessary here to engage in an extended analysis of the relation between science and industry, especially how much production does or does not owe to scientific theory. That problem has an extensive literature of its own.[40] The scientization of industry presented itself as a plain fact to contemporaries and can hardly be escaped if we attach any weight at all to the concept of a second industrial revolution.

Beer puts the matter in the strongest possible terms, though he does not exagerate:

"the creation of the factory laboratory...was an event whose historical significance goes far beyond the immediate effect of stimulating [chemistry and production]..the changes it brought about in the techniques of scientific research ...accelerated man's control over nature to such an extent that every major human institution has since been affected."[41]

Other historians have labelled either scientific inquiry or its application the engine of economic growth, installed first in the chassis of the Second Reich.[42]

These bold, but entirely defensible, assertions leave much room for nuances. What we might call new frontier proponents argue for the

[40] See for example, Alexander Keller, «Has Science Created Technology?», *Minerva*, (Summer, 1984).

[41] Beer, «Emergence», p.112.

[42] Meyer-Thurow, «Industrialization of Invention». Clive Trebilcock, *The Industrialization of the Continental Powers 1780-1914*, (London, 1981), p.64.

supreme importance of industrial innovation based on professional intramural research and development and the creation of new knowledge. The growth of in-house R&D was stimulated by its separation from routine testing, the inability to do innovation at the site of production due to scale and continuous process production and by the very nature of science-based industrial technology.[43] In contrast, other historians have insisted that it is not necessarily scientific knowledge on the research frontier that fed into industrial production. Indeed it could be fairly elementary science which transformed production in more important ways than new theories. Further, it was not necessarily the creation of knowledge as the ability to apply it which mattered most, a now thoroughly established fact which is the despair of those arguing for basic science funding in many nations today. In a pattern followed by eighteenth-century Britain and twentieth-century Japan, nineteenth-Germany excelled in applying other nations' breakthroughs; most notoriously the aniline dye industry itself saw the initial discoveries made in England.[44]

While intra-mural R&D was important, so too was the creation of extra-mural institutions and linking industry with extra-mural scientific research. In the decade either side of World War One, manufacturers in many industries became increasingly convinced of the merits of cooperative forms of industrial research, usually, though not only, via extra-mural institutions.[45] Here, undoubtedly Imperial Germany led the way. The Germans very successfully institutionalized a blurring of the distinctions among pure and applied science and technology, making the relationships among them more dynamic than elsewhere; the Americans swiftly followed, however.[46] Not just the big, R&D intensive firms — BASF and Siemens in Germany, Westinghouse and DuPont in the United States — needed and got university-trained technical people to transform their operations. So, too, did the much larger number of smaller firms which supplied the leaders. Trade associations played very important roles in this regard as, too, did the producer-goods sector in spreading new technology, both nationally and internationally.[47]

In a defensive response to the gains of new science-based industries,

[43] Christopher Freeman, *The Economics of Industrial Innovation*, (Harmondsworth, 1974), p.25.

[44] Mowery and Rosenberg, *Technology and the Pursuit of Economic Growth*, (Cambridge, 1989), pp.21-35. Trebilcock, *Continental Powers*, p.64.

[45] R. Fox, «France in Perspective: Education, Innovation, and Performance in the French Electrical Industry, 1880-1914» in Fox and Guagnini, *Industrial Performance*, pp.201-226. Sanderson, *Universities*, pp.20-21.

[46] J.A. Johnson, *The Kaiser's Chemists*, (Chapel Hill, 1990), p.5.

[47] Locke, *Practical Man*, pp.298-299. David J. Jeremy (ed), *International Technology Transfer*, (Aldershot, 1991).

older technologies, too, modernized.[48] Only older industries possessing the protection of lack of substitutable products could, in some cases, escape the gales of creative destruction. But the storm fence could be blown down by changes in markets, tariff changes, new technology to produce the same product or the creation of substitutes based on different raw materials.[49] In general, industry experienced an arms-race like spiral to get more science into production. The process seemed irreversible, at least until the shock of the Great Depression.[50]

How was science linked to industry? What is the gloss to be put on the phrase the application of science? Many of industry's scientists were in fact engineers; the failure to make this distinction perennially distresses the latter. Chemical engineering and the engineering task of designing process equipment more immediately linked science to industry than did basic research. As David Channel points out, «engineering science functions as a translations between the languages of science and technology...by necessity a translation is both an activity and a body of new knowledge»[51]. Engineering, by the time of the second industrial revolution, had itself been transformed in its content and methods by the impact and influence of science. By the eve of the second industrial revolution, the term engineering science had entered both the English and German languages and been codified in manuals.[52]

Exact measurement and the instrumenation and language which it demanded also linked science to industry. Here physics made its great contribution in Germany, offering three things. New physical theories and concepts formed directly part of industry's new knowledge base. The rigorous techniques of physical measurement developed in and for the research laboratory found ready application in and for industry. Higher education up to and including the Ph.D. level trained industry's scientists and managers, more so even than in the United States.[53]

The glass and electrical industries were both major consumers of science and played critical roles in the scientization of industry, producing new equipment and precision instruments. The second industrial revolution could not have occurred without its pyrometers and polariscopes and its micrometers. They were as characteristic as the first industrial revolution's

[48] W. Schivelbusch, *Disenchanted Night*, (Berkeley, 1988), pp.49-50.

[49] J.-L. Delaet, «La mécanisation de la verrerie à vitres à Charleroi dans la première moitié de XX siècle», in Kurgan van Hentenryk and Stengers, *L'Innovation Technologique*, pp.113-152.

[50] Beer, *Emergence*, pp.112-113.

[51] D.F. Channel, «Engineering Science as Theory and Practice», *Technology and Culture*, (1988).

[52] W.M. Rankine, *The Science of Engineering*, (London, 1857). M. Becker (ed), *Handbuch der Ingenieur-Wissenschaft*, (Leipzig, 1856-61).

[53] Cahan, *Institute*, p.12.

thickness of a shilling standard or steam engine indicator diagram.[54] Such instruments had very low costs relative to the efficiency gains they offered.[55] New instrumentation facilitated improved process control to improve quality, reduce waste of material inputs, reduce energy costs, reduce labour costs, raise rates of throughout and help in standardization. Measurements standardized in a laboratory allowed for the extension of the laboratory space to a wider «economic and political space»[56].

Not least important, process control and monitoring instrumentation allowed for the implementation of continuous-process production. The growth in the market for heavy chemicals, the rise of petroleum-based feed stocks, cheap electricity, improvements in materials and equipment for plant, as well as the new instruments all facilitated the change from batch to flow. The advantages of flow over batch included economies of scale, thermal efficiency, higher quality and more uniform outputs, labour-cost savings and resultant lower unit costs.[57] We may take the steel industry as illustrating this change. The switchover to continuous flow production of steel became linked to highly sophisticated technical specifications only intelligible in terms of scientific testing. Operations were broken down, standardized, routinized and recombined into continuous flow processes. These were monitored by semi-skilled work force and overseen by university-educated personnel, themselves the products of changed institutions with new curricula and new mandates.[58]

Role of the State

Le grand absent of Chandler's magisterial reconstruction of late nineteenth and early twentieth century capitalist economies is the state. What should be on centre stage, spotlighted, peeks in from the wings and makes fleeting appearances. Some of the roles played by the state in the second industrial revolution carried over from the first. The state had broadly to be permissive of capitalist strategies and, usually, tactics. In moments of crisis the state was expected to weigh in with coercive force at the behest of capital. However, the apotheosis of *laissez-faire* coincided with the climax of the industrial revolution in the 1840s. Afterwards, the rise

[54] Cattermole and Wolfe, *Horace Darwin's Shop*, pp.185-188.

[55] Stuart Bennet, «The Industrial Instrument—Master of Industry, Servant of Management: Automatic Control in the Process Industries, 1990-1940», *Technology and Culture*, (1991).

[56] A. Barry, «The History of Measurement and the Engineers of Space», *British Journal of the History of Science*, (1993).

[57] Freeman, *Industrial Innovation*, pp.143-145.

[58] M.Numer, «From Batch to Flow: Production Technology and Work Force Skills in the Steel Industry, 1880-1920», *Technology and Culture*, (1988).

of the regulatory state meshed nicely with new corporate schemes. The growth of the state included the presence of industry-oriented scientific and technical bureaux and, above all, the distribution socially of the overhead costs of training new industrial personnel.

Intense national rivalries helped lure the state into facilitating the second industrial revolution. Frequently the rhetoric of national (or imperial) competition was used to legitimate state activity. Thus if a nation lagged behind economically, science, so the argument went, could be used to make up the ground. If that nation then appeared to become a leader in its commitment to scientific and technical advance, its neighbours could be spurred into greater efforts. If the graduates of a nation's educational system emigrated in significant numbers, this brain drain had to be arrested by employing them at home. Conversely (or even simultaneously) if foreigners conspicuously filled positions which «ought» go to the native born, this triggered demands for educational reform oriented to the needs of a new economy. Statistical *legerdemain* could always be used to present a sorry picture of a nation's own commitment to science and technology as contrasted with some rival and thus justify increased state activity. Such games are of course played out in the science policy sphere to this day.

At least through the First World War, Germany was the most frequently cited model of how a strong and enlightened state should promote and could reap the benefits of close links between science and industry. Most notably the *Physikalisch-Technische Reichsanstalt* (PTR) redefined the form and function of a capstone national science body — a research body of exact science, not an academy of natural philosophy. Cahan has carefully explained the role of the PTR in German national integration and industrial advance through exact, standard measurement.[59] While scientists of the first rank (up to and including Einstein) worked at the PTR, service bureau work for industry, embracing both research and testing, in particular instrument calibration on a large scale, ranked chief amongst its activities. The *Reichsanstalt*'s emulators elsewhere included institutions such as Britain's National Physical Laboratory and the U.S. Bureau of Standards, state bodies which provided the ultimate metrology of industrial mensuration.[60] Indeed even Britain, usually cited as the great loser in the jump from the first to the second industrial revolution had any number of government bodies playing important roles in linking, especially, chemistry to industrial production: the Mint, the Admiralty, Woolwich, Inland Revenue (the first two with historic links to science).[61] Everywhere, government bureaux both assisted industry technically and also aided the state in regulating industry.[62]

[59] Cahan, *Institute*.
[60] Cattermole and Wolfe, *Horace Darwin's Shop*, p. 192.
[61] R. Bud and G.K. Roberts, *Science versus Practice*, (Manchester, 1984), p.106.
[62] Johnson, *Kaiser's Chemists*, p.14.

European states spent the decades after German and Italian unification preparing for a decisive clash of Empires. They did this not just by laying down battleships in steel but by building up universities in brick. Industry found much of value in both new and changed institutions of higher education and academic research. The education systems, for all that critics bemoaned a supposed ivory tower classics bias, accepted with remarkable eagerness and success a new mandate to serve economic and national needs.

In part, the scientific nature of industrial production made its problems intellectually interesting to academic scientists, while, in Harry Paul's striking phrase, «the factory...had become dependent on the faculty»[63]. The output of industrial scientists and engineers was so necessary to the manufacturing firms of the second industrial revolution as almost to be conceived of, with dubious rigour, as an additional factor of production.[64] Educational bodies gave students not just new knowledge but «the habits of order, accuracy, and rigour that had become the basis of the best industrial practice»[65]. Here the German Ph.D., with its emphasis not on past knowledge but exact method of inquiry after new knowledge, gained the lustre of an alchemist's stone, not just in the German lands but, especially, in the Anglo-Saxon world. The knowledge base of the industrial production was truly new wine in new bottles and the groves of academe were the vineyards.[66]

Depending on its relative success, the linkage of the academy and industry could develop as a virtuous spiral or be stuck in a vicious circle. As the scientific component of industrial technology grew so too did the need of industry for academic science. Universities became more and more attuned to industry needs and more willing to commit themselves to its problems. In turn, a more applicable academic science further stimulated an industry now receptive to the products, human and intellectual, of the universities.[67] That was the ideal. However the opposite could also occur. Productivity advance was difficult if the education system was not turning out appropriately trained scientific and technical personnel. But if there were no jobs and no demand for such personnel in more traditional industry, then the education system would have no incentive to produce graduates for industry.[68]

If reform of existing institutions proved too difficult a task or more innovative funding routes were needed, the option could be taken to found new institutions. That is exactly what was done and with striking success. Don't try to clean out the Augean stables to house your Ford or Daimler, build a garage. The U.S. Land-Grant Colleges, British red-brick universities and

[63] Paul, «Apollo».
[64] Baudet, «Engineers in Belgium».
[65] Paul, «Apollo».
[66] Sanderson, *Universities*, p.112.
[67] *Ibid*, p.13.
[68] Davis, «Late-comer».

above all the *Technische Hochschulen* represent prime examples of the new educational facilities of the second industrial revolution. They met the needs for personnel to supervise and design the physical plant of new, scientifically complex industrial production.[69]

The precise models for linking industry to university varied and to assess them is complex. One model linked highly specific programmes at particular institutions to the needs of dominant local industry. The United Kingdom and, especially, France seem to have favoured this appoach, Germany less so and the United States even less. Indeed this may have been a case of short-term gain for long-term pain, as shown by the greater success of the U.S. model built around unit operations — a set of basic physical transformations of materials by industrial devices common to a wide range of productive processes — as the basis of chemical engineering necessitated a break between engineering education and the industry-specific needs of any given productive process. That approach perfectly fitted the new structure of technical knowledge of the second industrial revolution. It must be seen as providing one of the keys to an eventual U.S. overtaking of Germany as the leader of industrial-oriented academic science and engineering.[70]

As mentioned, contemporaries, and most subsequent historians, have seen Germany as the European leader in linking its educational system to the needs of industry.[71] German chemical industry, academic and professional organizations such as the VDI were bound together in a favourable legal environment from which the Wilhelmine state derived great results.[72] German engineering in particular seemed to avoid the Scylla of French mathematical abstraction and the Charybdis of Anglo-American empiricism.[73] Correctly noting the class implications of these developments, Johnson observes that the new educational institutions turned out the «'new middle class' of engineers, technical bureaucrats, and industrial researchers to guide the modernization of the German economy».[74]

What of elsewhere in Europe? Recent historiography has tended towards a muting of the differences between Germany and its rivals, a pendulum

[69] Kranzberg, «Industrialization».

[70] J.C. Claude Guédon, «Conceptual and Institutional Obstacles to the Emergence of Unit Operations in Europe» in W. Furer (ed), *History of Chemical Engineering*, (Washington, 1980), pp.45-76. Compare, however, Colin Divall «Education for Design and Production: Professional Organization, Employers and the Study of Chemical Engineering in British Universities, 1922-1976» *Technology and Culture*, (1994), pp.258-288.

[71] Trebilcock, *Continental Powers*, pp.62-66.

[72] Freeman, *Industrial Innovation*, pp.48-53.

[73] E.T. Layton, «Science as a Form of Action: The Role of the Engineering Sciences», *Technology and Culture*, (1988), pp.82-97.

[74] Johnson, *Kaiser's Chemists*, p.13.

swing familiar to students of the first industrial revolution. In particular we now have a much more positive picture of the response of the French educational system to the need for new personnel.[75] The United Kingdom remains the most difficult case. The most critical assessments insist that Britain tried «to live through the Second Industrial Revolution with the tools of the First»[76]. Higher technical education in Victorian and even Edwardian Britain has been seen as caught in a squeeze between *élite* disdain for industrial pursuits and industrial and engineering preference for on-the-job training, pupillage and apprenticeship, prejudices not altogether gone.[77] Institutions such as the Society of Chemical Industry are portrayed as linking the separate academic and industrial realms, in the manner of the Lunar Society, more than melding them together.[78] Most students of chemistry in mid-Victorian England put their skills to work as analysts and production managers after only a very incomplete education; few had professional identities as «chemists».[79] Notoriously, the very word chemist has not established itself clearly in the English language in Britain, unlike North America, as defining a scientific pratictioner. This may, however, be too dark a picture. By the last two decades of the Queen-Empress's reign the most successful sectors of the U.K. economy had established good links with the academic world, a world no longer of any ossified Oxbridge duopoly.[80]

Social Consequences

The second industrial revolution would not merit its name if it had not had social consequences every bit as profound as its eponymous forebear. Part of those consequences consists in a transformed material culture resulting from the output range and lowered unit costs of transformed productive processes. The lifestyles enjoyed by the broad majority of women and men in the industrialized world, though of course not equally, are a consequence of the second industrial revolution, not the first. (Ominously, the third industrial revolution seems to offer only a cyber-spaced-out virtual reality.) Part, as well, are the class implications of new productive processes and their control. The second industrial revolution again remade the working class and above all created an enlarged and hegemonic middle-class.

[75] C.R. Day, «Education for Industrial World» in Fox and Weisz, *Organization*, pp.127-154. André Grelon, «The Training and Career Structure of Engineers in France, 1880-1939» in Fox and Guagnini, *Industrial Performance*, pp.42-64.

[76] Mokyr, *Lever of Riches*, pp.262-263.

[77] A. Guagnini, «Worlds Apart: Academic Instruction and Professional Qualifications in the Training of Mechanical Engineers in England, 1850-1914» in Fox and Guagnini, *Industrial Performance*, pp.16-41.

[78] Bud and Roberts, *Science versus Practice*, p.101.

[79] *Ibid*, p.99.

[80] Sanderson, *Universities*, p.11.

Under the influence of a too simplistic reading of Braverman et al. labour historians in particular have focussed on the process of deskilling. True, Taylorism in its several manifestations loomed large in the second industrial revolution with its continued separation of the conception of work from its execution. So, too, did the deskilling occasioned by scientific control of continuous processes. Workers became machine tenders, monitoring equipment, mere readers of dials and pushers of levers.[81] However, the vocabulary needed to discuss the refashioning of the labour process is much more complex, and must extend beyond «deskilling», «disempowerment» and «resistence»[82]. Not all managers used deskilling as a strategy and not all who did were successful. Indeed even from a managerial standpoint it may not have been the best strategy as the North American automakers eventually learned.[83] New technologies posed questions rather than provided answers about the place of labour in changed production. Some workers were reskilled and new, highly-skilled positions were created. Tasks could be combined rather than subdivided. Some workers possessing older skills were even empowered by technical change and many others consented to its implementation.[84] Old time iron puddlers and rivet drivers may have been colourful and their work songs part of a vigorous and lost proletarian culture. But the tasks they performed were back-breakingly strenuous and hideously dangerous, the disappearence of them not to be regretted.

The change from batch to continuous flow production illustrates many of these issues. «Reliance on worker skills placed limits on the scale of production» and virtually demands batch production.[85] The workforce in continuous-flow plants lacked the full hierarchy of skills as the least skilled materials-handling tasks were mechanized as thoroughly as the most skilled became eliminated, creating a more homogeneous semi-skilled force of machine tenders. However, it would be a serious error to underestimate the amount of skill in such quickly learned but slowly mastered semi-skilled jobs. Workers no longer needed physical, manipulative skills, but required «diagnostic skills».[86]These new skills and the enormous costliness of interruption of production gave workers real power and allowed them to command wages at a level adequate to join the middle class in tastes and material comforts.[87]

[81] Bennet, «Automatic Control».

[82] Robert L. Frost, «Labour and Technological Innovation in French Electrical Power», *Technology and Culture*, (1988), pp.865-887.

[83] Gospel, *Industrial Training*, p.3.

[84] Paul L. Robertson and Lee J. Alston, «Technological Choice and the Organization of Work in Capitalist Firms», *Economic History Review*, (1992).

[85] Numer, «Batch to Flow».

[86] *Ibid.*

[87] Frost, «French Electrical Power».

But it was engineers and industrial scientists, middle class in origin, who came to gain proximate control over production. At first they vied for control with traditional foremen. Routine testing and analysis of raw materials and quality control of output numbered among their first tasks. These tests slowly became more prevalent and shaded into process control. The training of university students meanwhile became more directly relevant to industry needs. University-trained personnel, from those with engineering degrees to full Ph.D.s, gained control over the proximate decisions of production, built in control via plant design and made the laboratory the locus of new product development and technical change.[88]

Instruments were to continuous-flow production processes what Taylorism was to the metal trades and assembly line.[89] Eager young graduates could not hope to match the by-eye (or ear or nose) judgements of the experienced worker. But they could better him by doing what they have been trained to do — conducting quantitative measurement using precision instruments. This had the effect of putting the entire discourse over production in terms comprehensible only to scientists and engineers.

Though the single social category of industrial scientists and engineers is delineated, the latter in fact were the quintessential figures of the second industrial revolution. Shinn has traced for us the changing meaning of the word *ingénieur*. In the 1830s he was a state employee, especially in the military. By the 1860s definitions also allowed for industrial engineers. The two meanings reached parity by the 1880s and by 1910 the word had a definition primarily restricted to industry and only secondarily to the military and state bureaucracy.[90] (Only the quite recent gutting of the passenger rail system has allowed engineer to overcome in the English language its primary association with driving a locomotive.) The professionalization of engineering related intimately to the bureaucratization of the corporation. Engineers became part of a managerial middle-class.[91] Indeed they set the model for middle class professionalization. Professions as Layton reminds us, «link bodies of knowledge to forms of action».[92] Engineers, both in reality and in self image, have been men and women in the middle. They stood between the scientific and the empirical. Engineers imagined and socially justified themselves as the group which was able to link science to production for human betterment.[93] Engineers, paid employees of corporations except for an *élite* of consultants, academic and journalists,

[88] Meyer-Thurow, «Industrialization of Invention». Numer, «Batch to Flow».

[89] Bennet, «Automatic Control».

[90] Shinn, «Profession».

[91] R. Torstendhal, «Engineers in Industry, 1850-1910» in Bernhard, *Science, Technology and Society*, pp.253-270.

[92] Layton, «Engineering Sciences».

[93] Shinn, «Profession».

self-consciously stood between capital and labour just as they stood between theory and application.[94] The second industrial revolution was their revolt.

Conclusions

The second industrial revolution, if not a watershed in human history of the magnitude of the first, is worthy of its label. It may properly be compared in many respects to the first industrial revolution. Professor Temin's programme is an entirely worthwhile one and is indeed more urgent now than when he suggested it almost a decade and a half ago.

We may first note the heuristic value of the concept of the second industrial revolution. Along with a possible medieval industrial revolution as described by Gimpel and White, an early modern one argued for by Nef and a CAD/CAM information-intensive third industrial revolution still ongoing, it provides information for us to understand *the* industrial revolution as either a unique event or a type of process.[95] A study of the second industrial revolution in all its aspects must include not just economic history, but business and labour history and the history of science and technology as well as the history of education and sociology of knowledge, to name only the most obvious candidates. Thus it provides a splendid focus for interdisciplinary studies.

The underdeveloped state of the topic's historiography allows almost unlimited scope for scholarly investigation. Some topics, however, stand out as especially critical. A proper chronology must be nailed down, both delimiting the second industrial revolution as a global phenomenon, determining its internal chronology (before and after World War One?) and determining the timing of events by country and sector. Just as the relationship of the industrial revolution to the existing pre- or proto-industrial economy and society continues to occasion lively debate so should the relationship of the second industrial revolution to the first. Doubtless this will infuse renewed vigour into the debate over the place of science and indeed of technical change in the industrial revolution. Recent work by Jacob in this regard suggests one fruitful avenue of approach.[96] The ideological contexts, which must of course be national, for the second industrial revolution must not be neglected. Professor Temin is almost certainly correct in wishing to link it to Progressivism in the United States.

[94] Grelon, «Career Structures».

[95] J. Gimpel, *The Medieval Machine*, (New York, 1976). Lynn White, Jr., *Medieval Technology and Social Change*, (Oxford, 1962). John Nef, *Industry and Government in France and England*, (Ithaca, 1957). B. Prosad (ed), CAD/CAM *Robotics and Factories of the Future*, (Heidelberg, 1987).

[96] M. Jacob, *The Cultural Meaning of the Scientific Revolution*, (Philadelphia, 1988).

But how does the second industrial revolution's modernization and empowerment of the technical middle class relate to, say, European fascism? And what can we say about the second industrial revolution in Russia and the USSR? Two generations removed from the end of a revolution is perhaps time enough past for a full blooded engagement in historiographic conflict.