Bourgeois scientific societies and industrial innovation in Britain 1780-1850

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It is commonplace that industrialisation in Britain from 1780 to 1850 was unplanned: it was entrepreneurs, and not central government or local authorities, who saw to it that technical innovation in industry occurred, thus giving an increase in productivity per head which in turn led to a substantial and progressive rise in real income per head[1]. This first industrial revolution, as it is often called, was not merely a matter of mechanical ingenuity epitomised by James Watt's steam engine. As the industrial revolution meant a transformation of the economy as a whole, it involved many inter-related factors such as availability of capital, foreign trade, the role of the banks, demographic movements, increasing urbanisation, agricultural change, the nature of the aristocracy, transport arrangements, and marketing devices. In this paper I shall not attempt the mammoth task of discussing the relation of science to each of these factors, profitable though that would be. Granted that one should be aware of the importance of all these and other factors in the process of industrialisation, I shall focus on the contribution to industrial entrepreneurship and innovation made by science on the supply side via bourgeois scientific societies. I shall not discuss the contribution of science to the expansion of otherwise unchanged industries or the effects of science on the demand side.

[1] EA Wrigley, *Continuity, Chance and Change. The Character of the Industrial Revolution in England* (Cambridge, 1988); P. Mathias, *The First Industrial Nation. An Economic History of Britain 1700-1914* (London, 1983).

My brief is the limited though important one of looking at bourgeois scientific societies as a possible motor of industrial entrepreneurship and innovation. Of course such societies were not the be-all-and-end-all of even middling-rich and aristocratic science in the period under review; but, given the cavalier and contradictory statements that have been made about them, they should not be ignored. They can be used as a strategic research site from which one may produce some clarification of the much-debated relation between science and industrial innovation.

Considerable confusion has been generated in the voluminous secondary literature by the way in which historians have defined science in Britain from 1780 to 1850 too narrowly. During the first British industrial revolution science was the socially organised attempt to set and to solve problems concerning the understanding and perhaps control of nature, the value of the problems and the adequacy of the answers being subject to social negotiation between all interested parties. It was thus an activity, and not just an end-product, which embraced many different features or elements which can be categorised arbitrarily under three headings. These were: a) science as general beliefs and assumptions, which provided a framework in which problems were posed and encouragement was given to persist in trying to find answers to them; b) science as techniques employed in solving these problems; and c) science as end-product, i.e. as public knowledge and answers, published in journals and books, to those problems.

In examining science as general beliefs and commitments, pride of place goes to the assumption that nature behaved in a law-like way and not arbitrarily: there was a consciousness of the universal laws and operations of nature inspired by Isaac Newton's supreme achievement of his universal law of gravity in the late seventeenth century[2]. It was widely held that these laws were discoverable, not by ratiocination, but by the empirical methods which had been given a robust philosophical underpinning, again in the late seventeenth

[2] CA Russell, *Science and Social Change 1700-1900* (London, 1983), pp. 103-113.

century, by another Englishman, John Locke. Subject to the qualification that objects were not simply seen but seen as something or other, empiricism ranged from observation to complicated experiments in which unnatural conditions were created or materials could be systematically tested. Empiricism in general was active and aggressive. In the world of science it was more informed, persistent, and exhaustive than that of the untutored craftsman; and it was associated with the belief that theories were not to be uncritically accepted but could be tested. Empiricism was compatible with the aphorism enunciated by Francis Bacon that knowledge is power, which when applied to science meant that *in potentia* it was useful in giving command over nature for the relief of man's estate and that there was a pervasive aspiration, not always realised, to apply science, in its various forms, to industry. More generally empiricism was often seen as the way in which to achieve progress, albeit limited; and was widely regarded as responsible for the cult of improvement characteristic of the period. Empiricism guaranteed that progress was possible and not a phantom.

Science was also a matter of techniques, some of which required manual or sensory skill in using apparatus which constituted the material base of the scientific enterprise. Apparatus occurred in at least four guises: physical and analytical instruments were deployed in research; professional ones by surveyors etc; pedagogic ones by teachers; and lastly, recreational ones such as the kaleidoscope in the home[3]. Some apparatus, though not all, could be used to make measurements and thus subject work with instruments to the quantifying spirit. In the early nineteenth century geology, a subject often assumed to be qualitatively descriptive, witnessed the invention of new measuring instruments such as the clinometer to measure the slope of rock strata and the portable aneroid barometer to measure heights above sea level. By 1850 a new technique of making thin slices of rock which could then be examined under a high-powet microscope had enabled palaeobotany to accelerate and petrology to

[3] GL'E Turner, *Ninteenth-century Scientific Instruments* (London, 1983).

come into existence. A development related to measurement was the increasing use of mathematics and statistics as a language in science [4]. Though the mathematicisation of some branches of experimental philosophy in the period is well known, it is not widely appreciated that in the 1840s some geologists were taking censuses of fossils, i.e. they were not merely recording which fossils occurred in certain rock strata but how prevalent they were. It was not an accident that statistical societies began to burgeon in the 1830s (Manchester 1833, London 1834, and the statistical section of the British Association for the Advancement of Science 1833) and that routine civil registration of vital statistics (births, marriages and deaths) began in England in the same decade.

A third facet of science was formal knowledge or research work published in books and journals. This category embraced a wide variety of types of public knowledge. Witness the reporting of a new phenomenon, such as electromagnetism by Michael Faraday in 1831; of a new substance such as chlorine by Humphry Davy in 1807; or of startling results or data such as the variation of the finches on the Galapagos Archipelago by Charles Darwin in the late 1830s. Sometimes publications involved promulgation of a new theory, a new hypothesis, a new concept, a new law (in the period often a descriptive summary of regularities established empirically), and even a set of fundamental principles which it was claimed by their author defined a subject. Thus the end-product of scientific investigation was not a standardised item: on the contrary it embraced different genres.

It is therefore misleading to assume that science in Britain was a monolithic entity and was just formal knowledge: it was an activity with many facets, some of which have just been described. Sometimes different historians have fastened on to a selection of these facets and assumed it to be central to science; they have defined science in such

[4] L. Daston, *The Reasonable Calculus. Classical Probability Theory, 1650-1840* (Princeton, 1988); T.M. Porter, *The Rise of Statistical Thinking 1820-1900* (Princeton, 1986); S.M. Stigler, *The History of Statistics. The Measurement of Uncertainty before 1900* (Cambridge, Mass., 1986).

a selective way that they have easily reached the conclusion about the particular relation between science and industrial innovation which all along they suspected to have existed. Thus we can understand how distinguished historians have arrived at diametrically opposite conclusions. On the one hand we have Ashby, Landes, and Von Tunzelmann who all believe that science and industry intersected from time to time but that the instances of intersection were few. On the other hand Ashton, Schofield, and above all Musson and Robinson all see a central role for science in the first British industrial revolution[5]. The first party tends to see science as primarily achieved formal research, sometimes abstract and theoretical. Not surprisingly its members have not been able to adduce many examples of science as published end-product being the source of technical invention and innovation: they have looked back beyond 1850 to try to see something analogous to modern research-and-development and not unexpectedly have not found it. The second party looks at science as chiefly beliefs, aspirations, and techniques; thus Musson and Robinson have been able to offer plenty of examples of the sustained and visionary yearning or intention to apply scientific knowledge to industry, of the prevalence of the technique of organised empiricism, and of an increasing number of agencies which diffused information about science and its application to industry. Clearly it was easy for them to postulate a strong connection between science and industrial

[5] E. Ashby, *Technology and the Academics. An Essay on Universities and the Scientific Revolution* (London, 1963); D.S. Landes, *The Unbound Prometheus. Technological Change and Industrial Development in Western Europe from 1750 to the Present* (Cambridge, 1969); G.N. Von Tunzelmann, "Technical progress during the industrial revolution" in R. Floud and D. McCloskey (eds), *The Economic History of Britain since 1700. Volume I: 1700-1860* (Cambridge, 1981), pp. 143-163; T.S. Ashton, *The Industrial Revolution, 1760-1830* (London, 1948); R.E. Schofield, *The Lunar Society of Birmingham. A Social History of Provincial Science and Industry in Eighteenth-Century England* (Oxford, 1963); A.E. Musson and E. Robinson, *Science and Technology in the Industrial Revolution* (Manchester, 1969). For penetrating overviews see: P. Mathias, "Who unbound Prometheus? Science and technical change, 1600-1800" in Mathias (ed), *Science and Society, 1600-1900* (Cambridge, 1972), pp. 54-80; and N. McKendrick, "The rôle of science in the industrial revolution: a study of Josiah Wedgwood as a scientist and industrial chemist" in M. Teich and R. Young (eds), *Changing Perspectives in the Histoy of Science. Essays in Honour of Joseph Needham* (London, 1973), pp. 274-319.

innovation because they focussed on science as general beliefs and aspirations and as technique.

It has been asserted that the burgeoning of bourgeois scientific societies in Britain from 1780 to 1850 was a motor of industrial innovation in those years. This paper examines just three sorts of voluntary society, each of which prima facie seems favourable to the view that there was indeed a strong and fruitful connection between science and industrial entrepreneurship and innovation. Firstly we shall scrutinise provincial general scientific societies, often called lit-and-phils, in industrialising areas such as Birmingham, the Potteries, Manchester, Glasgow, and Bradford. Secondly, we shall look at disciplinary scientific societies and their connection with industrial innovation, using the example of geology and mining. Thirdly, we shall investigate the place of engineers and engineering in the only national pressure group for science which existed in the period, the British Association for the Advancement of Science founded in 1831.

The importance of Manchester as the shock-city of the industrial revolution has long been recognised in the nick-names of Cottonopolis and Engelschester. Some economic historians, such as Rostow, have found it possible to locate in Manchester in the early 1780s the all-important take-off into self-sustained economic growth via the development of the cotton industry as a leading sector [6]. At the same time, historians of science have long known that the Manchester Literary and Philosophical Society (henceforth MLPS), founded in 1781, was the first enduring provincial general scientific society. This chronological propinquity has lured some historians into assuming a causal relation between the rise of organised science in Manchester and its industrialisation. Thus Ashton gave an economic interpretation of the MLPS, assuming that as a handmaid of industry it was devoted to improvements in methods of production and that consequently manufacturers dominated it [7]. This economic

[6] W.W. Rostow, *The Stages of Economic Growth* (Cambridge, 1960); Rostow (ed), *The Economics of Take-off into Sustained Growth* (London, 1963).

interpretation was also applied to the Lunar Society of Birmingham by Schofield and by Musson and Robinson, who claimed that its importance lay in its advantageous syncretism of pure science and advancing industry. These historians were impressed by the Society's repeated proclamations of intent to apply science to manufacturing industry (or to medicine) and by the presence of such leading industrialists as Matthew Boulton, James Keir, James Watt and Josiah Wedgwood in the fourteen-strong membership.

The economic interpretation of provincial general scientific societies in industrialising areas was not without its critics but it was only in the early 1970s that a sustained revisionist critique and an alternative cultural interpretation were launched. Shapin led the way in 1972 with his examination of the shortlived Pottery Philosophical Society, 1819-35, which was unable to withstand competition from the local mechanics' institute because the latter had greater cultural uses [8]. He argued strongly that the utility of science had to be prised loose from its purely economic associations. Shapin was soon followed by Thackray who tried to show the sterility of any simple thesis about the industrial purposes of the MLPS from 1781 to 1851 when Owens College (now the University of Manchester) was opened [9]. In order to demonstrate that the MLPS had no direct bearing on industrial innovation, Thackray employed the technique of prosopography to study the collective biography of the members from 1781 to 1851. He concluded that learned professionals, such as medical men, clergymen and teachers provided leadership of the Society until the 1830s when engineers began to be important. Thus he qualified Ashton's view that the MLPS was run by manufacturers and merchants. Thackray also analysed the scientific topics which the more active manufacturers and merchants pursued and even with respect to the end of the period concluded that, if roughly half of them worked on

[7] Ashton, *Industrial Revolution,* pp. 16, 21.

[8] S. Shapin, "The Pottery Philosophical Society, 1819-1835: an examination of the cultural uses of provincial science", *Science Studies,* 2 (1972), pp. 311-336.

[9] A.W. Thackray, "Natural knowledge in cultural context: the Manchester model", *American Historical Review,* 79 (1974), pp. 672-709.

areas of science related to their economic interests, about half did not. For example, William Fairbairn, the structural engineer, published on the strength of materials, a topic central to his occupation as a builder of mills and bridges. On the other hand James Nasmyth, of steam-hammer fame, saw science as recreation and as a welcome change from the noisy tumult of the factory: his field of research was the study of silent nebulae of stars. Having severely qualified the economic interpretation of the MLPS, Thackray then argued that it had cultural uses which were far more important than economic utility either *in potentia* or *in actu*. The principal cultural uses he invoked were the social legitimation of marginal men, rational entertainment, theological edification, social common-ground or anodyne, and cultural affirmation. Thus, he argued, science was pursued by the members of the MLPS not because it acted as a technical agent but because it served their cultural interests.

The revisionist approach of Shapin and Thackray has been applied to Glasgow and Bradford with even more corrosive results. The Philosophical Society of the former was founded in 1802 to promote local trade and manufactures and its membership was dominated by manufacturers, merchants and artisans [10]. It soon ran into trouble, with irregular meetings, until in 1834 it was taken over by the distinguished professoriate from the University and Anderson's University, and by the leading local medical men and corporations, who had all previously ignored it. Only in 1842 did it begin to publish a journal. In its opening thirty-two years, the Glasgow Society did little to increase the town's economic prosperity; until the learned professionals appeared, the Society did not even function at a minimal level: with few papers, few speakers, no publications, and irregular meetings it was redolent of the Pickwick Club. Left to themselves Glasgow's businessmen might have been anxious to improve the arts and sciences, either as performers or audience, but their ambition was quickly shown to be chimerical.

[10] J.B. Morrell, "Reflections on the history of Scottish science", *History of Science*, 12 (1974), pp. 81-94, especially pp. 88-94.

Ironically it was the Glasgow professoriate, especially William Thomson (later Lord Kelvin), who from the 1850s made the Society a vehicle for both pure and applied science; indeed in his own life Thomson revealed the interdependence between science, engineering and industry [11].

Bradford provides a *reductio ad absurdum* of the economic interpretation of provincial general scientific societies [12]. The town grew rapidly from 1800 to 1850, with a ten-fold increase in population. It became the centre of the world's worsted textile industry and with its various squalors it was Yorkshire's equivalent to Lancashire's Manchester. In one respect, however, the towns were contrasting: Manchester was a city of science, but in Bradford, socially bottom-heavy, science as an organised cultural formation was fragile. The history of organised science in Bradford until the mid 1860s was one of struggling ephemerality. The first lit-and-phil, explicitly industrial in its aims and dominated by local industrialists, lasted from 1808 to 1810; and the second, which mixed the economic motive with theological edification, moral improvement, and local pride, lasted no more than a few months in 1822. Only with the contingent arrival in Bradford of a new vicar, William Scoresby, who joined forces with William Sharp, the senior surgeon at the Infirmary, was it possible for a third lit-and-phil to be formed in 1839. It lasted only four years: in 1843 Sharp left for greener pastures, leaving Scoresby to suffer a nervous breakdown the next year. As elsewhere learned professionals such as a clergyman and a medical man were needed to launch and sustain a local scientific society; by themselves local manufacturers and merchants were not sufficiently interested or competent to do so. The Bradford case pours a heavy *douche* of cold water on the idea that provincial science at the savant level in an industrialising area either directly served industry or was directly stimulated by it. Indeed in Bradford industrialisation, with its rapid

[11] C. Smith and M.N. Wise, *Energy and Empire. A Biographical Study of Lord Kelvin* (Cambridge, 1990).

[12] J.B. Morrell, "Wissenschaft in Worstedopolis: public science in Bradford, 1800-1850", *British Journal for the History of Science,* 18 (1985), pp. 1-23.

population growth and urbanisation, was extremely dislocating and disrupting In a shanty town such as Bradford people were aggregated but aggregated in an atomistic, dissociating way. Thus industrialisation produced in the case of Bradford a small, beleaguered and divided middle class which found it difficult to promote public science: it was small because of the nature of the demographic changes taking place; it was beleaguered because of the class hostilities rife in the town; and it was divided because of vehement religious and political conflicts which were exacerbated by the problems produced by industrialisation. For these reasons industrial innovation in Bradford was not stimulated by its public science; instead the dislocations produced by industrialisation destroyed or severely inhibited science. Bradford did not offer the leisured calm and the public order which favoured the expansion of the scientific spirit in non-industrial towns such as York [13].

Of course, quirky localism remained important in Victorian science so that different places nourished a public scientific life *sui generis:* one would not expect the lit-and-phils in Birmingham, the Potteries, Manchester, Glasgow and Bradford to be identical. These industrialising areas differed in population size, population growth rate, industrial structure, occupational characteristics, class complexion, economic vulnerability, geographical location, existing local scientific traditions, the nature and number of competing cultural groups, the relation to the metropolis, the contingent presence of leading savants, and local political and religious interests [14]. During the first British industrial revolution, there was no identikit lit-and-phil: instead localism and diversity were prevalent and sometimes jealously guarded. Given such conditions it is idle to even expect that all provincial general scientific societies promoted industrial innovation; and the case studies just described make clear

[13] A.D. Orange, *Philosophers and Provincials: the Yorkshire Philosophical Society from 1822 to 1844* (York, 1973).

[14] I. Inkster, "Introduction: aspects of the history of science and science culture in Britain, 1780-1850 and beyond" in I Inkster and J.B. Morrell (eds), *Metropolis and Province. Science in British Culture, 1780-1850* (London, 1983), pp. 11-54.

that an economic interpretation alone is insufficient and must be supplemented by a cultural one.

The relation between the British mining industry and British geological societies also seems promising if one is looking for a propitious relation between organised science and industrial innovation. The importance of metal ore and coal mining in the first British industrial revolution has never been denied and Britain continued to lead Europe both as a producer and consumer of coal per head of population. At the same time geology was so popular in Britain that it was soon institutionalised, a process that began in 1807 with the foundation of the Geological Society of London, the first national geological society to be founded in Europe. It was widely assumed that geology had great practical and commercial importance. After all, British geology from 1780 to 1850 was concerned with the delineation of the strata of the United Kingdom. In precisely those decades the industrial revolution not only consumed coal but exploited the earth for new minerals and metals and dug into it when making canals, roads, and railways. Furthermore public statements about the utility of geology for agriculture, mining, road-building, and national industry in general, were commonplace. Yet in a recent survey Porter has claimed that such fulsome rhetoric was belied by the brute realities [15]. In his view British mining contributed little to the science of geology and geology aided the practice of mining even less. Porter's interpretation has been implicitly endorsed by the more recent work of Flinn and Church on the British coal industry [16]. They show that between 1780 and 1850 the greatest technical advances lay not in the application of geology but in mechanical access technology, which enabled the coal to be reached and worked in safer conditions, and in operational methods, which involved the laying out of

[15] R.S. Porter, "The industrial revolution and the rise of the science of geology" in Teich and Young, *Changing Perspectives*, pp. 320-343.
[16] M.W. Flinn, *The History of the British Coal Industry. Volume 2. 1700-1830: The Industrial Revolution* (Oxford, 1984); R. Church with the assistance of A. Hall and J. Kanefsky, *The History of the British Coal Industry. Volume 3. 1830-1913: Victorian Pre-eminence* (Oxford, 1986).

workings and moving mined coal to the surface. Boring for coal was often literally exploratory; and in north-east England in the 1830s and 1840s it was viewers who pioneered the practice of making several bores as part of a single exploration in order to discover whether coal seams were dipping and faulted. The histories of metropolitan geological societies seem to be in accord with Porter's claims; yet those of provincial economically-motivated societies in mining areas are not, provided that intention, an indicator of consciousness, is assumed to be as historically important as manifest achievement.

There is no doubt that the Geological Society of London was the most powerful body in British geology via its journals and its famous discussions. It was regarded as a model learned society but it was also a gentlemen's club for men of secure and sometimes great income who dictated the Society's ethos and ran it. Gentlemen free and unconfined had the leisure to pursue months of field work full-time and unconstrained by the restrictions of an occupation: for them geology was a vocation for life and not a livelihood. Surveyors, mine owners, and engineers were not key fellows, the exception being John Taylor, the doyen of Cornish mining. It is highly significant that it was only in 1831 that the Society recognised the aged William Smith, a mining engineer, canal surveyor and agricultural improver, as the father of English geology because he was the first to teach and to use the notion that strata could be identified by their characteristic fossils. Even then it did not elect him to its fellowship. Generally it seems that lowly and sometimes impecunious practical mining men were ostracized, slighted, or at best coopted by the superior and wealthy gentlemen of science who devoted themselves not to economic geology but to general stratigraphical problems. For instance, the characteristic work encouraged by the Society in the 1830s was focussed on what came to be known by the end of the decade as the Cambrian, Silurian, and Devonian geological systems [17]. The London

[17] M.J.S. Rudwick, *The Great Devonian Controversy. The Shaping of Scientific Knowledge among Gentlemanly Specialists* (Chicago, 1985); J.A. Secord, *Controversy in Victorian Geology. The Cambrian-Silurian Dispute* (Princeton, 1986).

brethren of the hammer generally neglected coal formations and mining areas. Of course they visited coal mines and examined exploitable mineral veins, but their chief interest was to use the data acquired not to discover new coal seams but illuminate the general geology of the area in question. In 1831 and 1834 specialist geological societies were set up in the Irish and Scottish capitals respectively. Both were devoted primarily to polite geology. In Dublin academics from Trinity College founded and ran a society which, while not indifferent to possible economic development in Ireland, was mainly concerned with Irish stratigraphy. The Edinburgh Society was largely composed of businessmen who wished to adorn and dignify their leisure hours via geology; they gave negligible attention to the Lothian coal-field which was on their doorstep.

In the provincial mining areas a different emphasis was apparent [18]. By the late 1830s there were geological societies in Cornwall, Newcastle-upon-Tyne, West Yorkshire, and Manchester, where practical men were often the leading activists and were explicitly dedicated to what at the time was known as economic geology. Indeed in the 1830s and 1840s economic geology enjoyed recognition by government in the forms of the Geological Survey (founded 1835), the Museum of Economic Geology (f. 1835), the Mining Records Office (f. 1837), and the Royal School of Mines (f. 1851). But aspiration was one thing and achievement another, and this difference was compounded by the localism and diversity which pervaded British science. Hence these provincial geological societies, though often sharing the same aims, varied in the success with which they implemented their purposes. The first was the Royal Geological Society of Cornwall founded in 1814 in Penzance where local mining men, physicians and gentry combined to study local economic geology [19]. Even though some of its leaders had experience of the

[18] J.B. Morrell, "Economic and ornamental geology: The Geological and Polytechnic Society of the West Riding of Yorkshire" in Inkster and Morrell, *Metropolis and Province,* pp. 231-256, has a synoptic introduction.
[19] D. Crook, *The Royal Geological Society of Cornwall. Geology in Early Nineteenth-century Cornwall,* Open University PhD, 1990.

famous mining academies in central Europe, it failed to fulfil its own stated aims of completing a geological map of the county, of establishing a mining records office, and of setting up a mining school. Less ambitiously its published journal produced important data on local mineralogy, especially mineral veins, and on mining technology.

The Natural History Society of Northumberland, Durham, and Newcastle-uponTyne, founded in Newcastle in 1829, belied its title: it was founded as a splinter group from the Newcastle Lit-and-Phil to give greater attention to the geology of the north-eastern coalfield, then the most productive in Britain. It aimed to produce a large-scale map of sections of this coalfield and to establish a local mining records office. The chief protagonist of this ambitious scheme was John Buddle, known as the king of the coal trade for his innovations in mining practice, a man who in himself fruitfully combined economic geology and mining technics. As in Penzance, the Newcastle society had a propitious social composition, embracing in this case mining men, clerics, aristocrats, gentlemen, and the professional and commercial bourgeoisie. Even so most local mine owners and managers did not share Buddle's enthusiasm for making public the geological details of their own mines; presumably they regarded him as a voracious competitor who was trying to elicit from them their jealously guarded secrets of success.

In the late 1830s two societies, which later collaborated with only limited success in producing a section across the Pennine hills which would show the mutual relations of the Lancashire and Yorkshire coalfields, were established in central northern England. These were the Manchester Geological Society (f. 1838) and the Geological and Polytechnic Society of the West Riding of Yorkshire (f. 1837), both of which were founded in part to correct the neglect of local geology by the lit-and-phils in Lancashire and Yorkshire. The Manchester Society, dominated by the professional bourgeoisie, was particularly concerned with what it called practical, useful, and economic geology. In particular its first aim was to assist 'any geologist and miner ... to predict with tolerable accuracy what is to be found in any locality', an ambitious hope which was even more difficult to achieve than its second one of preventing fruitless searches for workable coal[20]. The Yorkshire Society was even more utilitarian: dominated by members of the West Yorkshire Coal Owners' Association, it aimed to collect, record, and collate geological and mechanical data pertinent to the Yorkshire coal measures and coal trade. After a vigorous start, the mining geology programme ran into difficulties and was replaced in the 1840s by ornamental geology. It seems that the aim of correlating the various seams of coal and ironstone in Yorkshire, via the production of geological maps and sections, was widely ignored because of the pervasive belief in coal mining that secrecy served competitive capitalism best: publication of local geological maps etc. was seen as industrial espionage. In any event, many mines possessed no written records. Though many mine owners joined the Yorkshire Geological Society, they were mainly passive members; few of them divulged and were able to discuss local geological information. Moreover, the active performers failed to sustain their programme of economic geology: they ran out of data when they had described their own locality; and, being deliberately isolated from metropolitan and provincial polite science, they could not act as interpreters of the limited data the Society accumulated. In addition, the geology of the Yorkshire coal area was not easily attacked: on such an important matter as the geology of the valley of the River Don the Society was in disarray. It also has to be noted that Thomas Wilson, the leading figure in the early Yorkshire Geological Society, suffered spectacular financial failure as a mine owner; and that important innovations in Yorkshire coal mining, such as sinking deep pits through the magnesium limestone to the concealed coal underneath, took place without reference to the Society. Thus the Society appeared incompetent or irrelevant. In sum, therefore, a distinction has to be made between societies devoted to pure geology and those concerned with its applied aspects. In the former, gentlemen or those aspiring to

[20] R.H. Kargon, *Science in Victorian Manchester. Enterprise and Expertise* (Manchester, 1977), pp. 24-27 (25).

that status tended to dismiss practical men and to ignore the practical applications of geology. In the latter the aspiration to pursue economic geology was undoubtedly strong; but ambition was not always matched by capacity and results because the *laissez-faire* nature of British capitalism in the mining industry produced a widespread suspicion of interference by external experts, whether mines inspectors or societies devoted to economic geology.

A third type of voluntary society worth examining is the national pressure group, of which there was only one in the period, namely the British Association for the Advancement of Science founded in 1831[21]. This was not a localised affair but the chief representative of the British body scientific; as a national peripatetic assembly it met for one week in each year in a different place. Initially it descended on academic towns, but from 1837 it invaded such emporia of industry as Liverpool, Newcastle-upon-Tyne, Birmingham and Manchester. It was not an exclusive learned society but an accessible association. Its aim was to advance science by whatever means its leaders deemed appropriate; as such it was the first national pressure group in British science. It needed a big membership in order to be visible, credible, and powerful. When it met in industrial towns, it solicited the cooperation of local industrialists in raising funds, in making local arrangements, in opening the doors of their establishments to the visiting philosophers, in mounting exhibitions of models of mechanical contrivances and products of local industry, in writing guides to the local attractions, and in organising excursions to some new engineering marvel. Superficially it seemed that the natural philosophers or scientists (a word coined in 1833) in the Association were making common cause with manufacturers and engineers, and that in the Association there was therefore a desirable inosculation of theory and practice. After all the Association prospered mightily in the 1830s and 1840s, which were the very decades in which Britain

[21] J.B. Morrell and A.W. Thackray, *Gentlemen of Science. Early Years of the British Association for the Advancement of Science* (Oxford, 1981), especially pp. 256-266, 472-474, 497-500, 505-508.

was consolidating her position as the workshop of the world through such means as the railway boom, the introduction of iron steamboats, and the development of the electric telegraph. *Prima facie* one would expect that manufacturers and engineers would have been important in the Association not just as members but in running it; and that in exchange the Association would have tried to promote applied science.

Yet again, however, chronological propinquity proves to be deceptive: as often happened elsewhere in British science, manufacturers and engineers were coopted by a controlling coterie of gentlemen that coterie maintained and shaped the Association to serve its own interests and to promote its views about the science which the Association existed to advance. It was a clique of gentlemen of science who saw that geographical mobility, publicity, size, spectacle, accessibility, and women could be used to form a British Parliament of Science. At the same time this coterie tried to formulate and promulgate what the Association should advance and what its members should study. Thus the social and intellectual features of the early Association were made and sustained by a circle of people joined together and separate from the ordinary rank-and-file membership, whose interests were not entirely ignored but where desirable were accommodated by that circle.

Some of the governing coterie were active in applied science but they were in a minority. David Brewster, the instigator of the Association, was keen on reforming the patent laws in order to give inventors such as himself proper financial reward and protection. Though he was a professor at Cambridge, Charles Babbage designed calculating engines. Neither was an industrialist. Indeed in the coterie there was only one practical man by occupation, namely, John Taylor the mining entrepreneur who for years was Treasurer of the Association. The social and intellectual composition of the coterie was responsible for the ambiguous place afforded to one of its scientific sections, that for mechanical science established in 1836. Only when the Association was safely launched did its managers embark on a policy of co-opting manufacturing interests and of visiting industrial towns. The mechanical science section, known as section G, brought together university teachers and practical men, with the former firmly in control. Engineers were well represented in the lower ranks of section G but the meanings and direction of section G's work were not controlled by them. The gentlemen philosophers were so in charge that the section was externally criticised for not being practical enough, yet they skilfully encouraged engineers and manufacturers to provide resources for research in mechanical science. For instance railway companies provided rolling stock, rails, and the use of lines for experiments to establish railway constants and data. Engineers were also valuable in arranging exciting technical spectacles and exhibitions which made material progress visible to those attending the Association's meetings. Not all engineers and manufacturers welcomed these exhibitions of inventions. At Birmingham in 1839 James Watt 2 had no truck with the Association's technical exhibition: it was not only puerile but injurious to his economic interest to reveal trade secrets. Watt was not alone in perceiving the difference between the entrepreneur's concern with secret mechanical arts and that of the scientist in publicly accessible and publicly promoted mechanical science; and he sensed that there was a danger in opening up to free enquiry technical processes which previously had been kept deliberately concealed, private, and exclusive.

Though there were in the late 1830s and early 1840s many research reports produced by volunteers, mainly engineers, on iron technics, such as studies of rusting, section G almost expired in the late 1840s just before the Great Exhibition of 1851 clinched Britain's position as the workshop of the world. Section G revived in the early 1850s and only in the early 1860s was it able to provide the first engineer, the veteran Fairbairn, to occupy the Association's presidency. In two other ways the Association recognised mechanical science but kept it in a subordinate position. The Association was the first scientific body to give regular research grants from its own funds (from 1833) and it was an effective lobbier of government on behalf of British science. About 20% of the Association's total research allocation was spent on supporting section G workers, the two most important fields being the strength of iron and the shape of ships. The former reflected the importance of iron as a ubiquitous material in the 1830s and its most characteristic expression was the research of Eaton Hodgkinson and Fairbairn on the contentious matter of the relative properties of iron produced by hot and cold blast furnaces. John Scott Russell's work on the characteristics of waves and the related question of the contours of ships was the second most expensive piece of research paid for by the Association in its opening two decades. It was concerned not only with iron steam boats which began to be introduced in the 1830s but also with wave phenomena which then were of great interest to many of the leading savants in the Association. Russell's results contradicted traditional ship-building lore and eventually overturned it: using Association research grants, he confirmed empirically the theoretical deduction he had made that the speed of a ship would be maximised by thin sharp prows, full-sterns, and maximum breadth amidships. His famous ship Great Eastern was indeed a child of section G. With respect to lobbies of government, the Association was less active in promoting engineering. Even such an obvious candidate as patent law reform was not raised with government until the late 1850s. Only about one in ten of the Association's lobbies reflected the concerns of section G and characteristically were concerned with the preservation of records of railway sections and those pertaining to mining. The gentlemen of science who ran the Association were simply not interested in prodding government to promote applied science and industrial innovation.

Though engineering was useful to the Association in that it made material progress manifest, though the Association met in the emporia of industry from the mid 1830s, though the Association needed the financial support of engineers and manufacturers, and though it relied on local resources which local industrialists could muster, the Association gave a qualified status to mechanical science and implicitly defined mechanical arts as beyond its aegis. For the Association theory was superior and practice inferior. As William Whewell proclaimed, technical innovation was the comely and busy mother of science, which was a daughter of far loftier and serener beauty. Thus in Britain's first national pressure group for science engineers and mechanical science were usually tolerated for their uses but on occasion were encouraged when purposes defined by the controlling gentlemanly coterie to be higher than that of industrial growth were being pursued.

The overall conclusion, from this admittedly selective survey of three sorts of bourgeois as opposed to artisan scientific society and their relation to industrial innovation and entrepreneurship, is that until the 1830s gentlemen and not entrepreneurs ran them and that their foci of interest were more polite than economic. From the 1830s industrial entrepreneurs were more prominent in the coteries which ran scientific societies and industrially applicable knowledge was more persistently sought though not often achieved. In a few areas, such as iron technics and ship-construction, those few engineers who were capable of functioning as performers in scientific societies produced research results which led to economically-useful published knowledge or a technical innovation. Some entrepreneurs, in contrast, were indifferent or hostile to scientific societies. Others were members of scientific societies but did not direct policy, deliver papers, and publish research; instead they constituted the audience for science and in that role were exposed to rhetoric and information about the desirable application of scientific knowledge to industrial innovation as well as to notions concerning science as beliefs and as technique which *in actu* as well as *in potentia* were industrially useful and innovative.

This overall conclusion is in harmony with the interpretation offered by Mathias who has argued that by and large innovations were not the result of the formal application of applied science: the quick wits and clever fingers of anonymous untrained artisans were more important than scientific knowledge in most fields. Where science did contribute to innovation, it did so usually via its methods and not through formal knowledge[22]. My conclusion is also compatible with

[22] Mathias, "Prometheus"; Mathias, *Industrial Nation,* pp. 123-130; Mathias, "Science and technology during the industrial revolution: some general problems", *Proceedings of the Sixth International Economic History Congress* (Copenhagen, 1978), pp. 104-109.

McKendrick's insistence that, even in the case of such a scientifically-absorbed industrialist as Wedgwood, his economic success depended more on the pull from demand than on push from scientifically-initiated innovation on the supply side. Such a view acknowledges that Wedgwood's science in the form of informed empiricism played a necessary but not sufficient role in his economic success[23]. My interpretation is also in harmony with the view of Inkster who has stressed the pervasiveness of what he calls steam intellect, a term derived from Thomas Love Peacock's *Crotchet Castle* published in 1831. Inkster believes that, irrespective of motivation, there was a wide diffusion of scientific and technical information through the various layers of British society quite separate from formal training given by schools and universities. Inkster goes on to claim that steam intellect, chiefly though not exclusively represented by the mechanics' institute movement, generated a high level of scientific and technical awareness, encouraged a ready diffusion of ideas and techniques between regions, and provided a minimal critical mass for technical innovation and adaptation[24]. Finally my interpretation is consonant with the views of those who have studied the rise of the new industries of fine chemicals, especially dyestuffs, and of electrical goods from the 1870s on the European continent and especially in unified Germany. Historians such as Landes and Trebilock have emphasised that it was in the second half of the nineteenth century that systematic ties were established between science and industrial practice, that these ties were cognitive, and accelerated the pace of invention[25]. The new industries were based

[23] McKendrick, "Role of science".

[24] I. Inkster, "Introduction: the context of steam intellect in Britain (to 1851)" in Inkster (ed), *The Steam Intellect Societies. Essays on Culture, Education and Industry circa 1820-1914* (Nottingham, 1985), pp. 3-19; Inkster, "Cultural enterprise: science, steam intellect and social class in Rochdale circa 1833-1900", *Social Studies of Science*, 18 (1988), pp. 291-330.

[25] Landes, *Unbound Prometheus*, 323-326; C. Trebilcock, *The Industrialisation of the Continental Powers 1780-1914* (London, 1981), pp. 22-111 (64); L.F. Haber, *The Chemical Industry during the Nineteenth-Century. A Study of the Economic Aspect of Applied Chemistry in Europe and North America* (Oxford, 1958), especially pp. 63-73, 80-87, 128-136; G. Meyer-Thurow, "The industrialisation of invention", *Isis*, 73 (1982), pp. 363-381.

on science as knowledge, whether published in journals by academics or created by research teams in the new research-and-development laboratories of heavily capitalised and often cartelised firms. Particularly in fine chemicals in Germany, innovations were the result of the formal application of science pursued by researchers and managers trained in universities and technical high schools *(technische hochschulen)*. As Trebilock has rightly stressed, high-level scientific team research was at the epicentre of German industrial growth. The German capacity for technical innovation based on research-and-development reached its apogee before the first world war with the Haber-Bosch process for the industrial synthesis of ammonia directly from its two component elements, nitrogen and hydrogen[26]. It took Fritz Haber, an academic at the Karlsruhe Technical High School, no less than six years to discover the conditions under which the synthesis could be carried out. For a further four years the development work, concerned with scaling up Haber's laboratory research, was carried out by Carl Bosch of Badische Anilin und Soda Fabrik; and the plant opened in 1913 was so large, complicated, and expensive that only the dreibund of Badische, Bayer, and Agfa, could afford to pay for it. The Haber-Bosch process is often referred to as a science-based innovation. Perhaps it would be better to designate it a research-and-development innovation to distinguish it from those innovations in British industry 1780 to 1850 which were also science-based but different in that they were usually indebted to science as beliefs and as technique.

[26] L.F. Haber, *The Chemical Industry 1900-1930. International Growth and Technological Change* (Oxford, 1971), pp. 90-97.