Mental Capital: Transfers of Knowledge and Technique in Eighteenth Century Europe

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1. Introduction

> 'Savants and students should participate as much as they can with other people and in the world'.
> [G.W. Leibnitz, 1669].
> 'It may be seriously argued that, historically, European receptivity to new technologies, and the capacity to assimilate them whatever their origin has been as important as inventiveness itself'.
> [Nathan Rosenberg, 1982].

The economic history of medieval Europe was dominated by the *diffusion* of basic technologies — the water wheel and wind mill, the heavy plough, the three-field system, the horseshoe and harnessing. What was new in the growth of Europe was not invention - many of the technologies had been long known - but their diffusion and assimilation. Many of the new technologies originated in China, but did not diffuse there. This might be explained in terms of underlying economic structures. In Europe, new technologies could often be applied to a *variety* of existing productive pursuits. For instance, in China the water wheel was used principally for blowing bellows in metal works. In Europe the same wheels were increasingly used for not only grinding but for the preparation of malt, the fulling of cloth, the sawing of wood and the production of silk thread. Similarly, the Chinese and Europeans became acquainted with the Persian (vertical axle) windmill at approximately the same time, the XIIth or XIIIth centuries. Although the windmill was not commonly used in China, in Europe it was *adapted*, first by mounting the sails on a horizontal axis, and secondly by developing the tower structure. Adaptation led to adoption. The reason for this disparity of experience almost certainly lies in the fact that in Europe the windmill satisfied a multitude of growing demands — silk, ribbons, fulling and calendering cloth, rolling copper plates and so on.

Technology transfer is the movement of a technology or product from the context of its original invention and diffusion to a different economic context, and is normally conceived of as occurring between nations. [1] Obviously enough, many of the inducements and barriers associated with technological diffusion within an industry are common to such transfers. However, the process of transfer generally does involve a variety of transfer mechanisms and environmental considerations not normally associated with industry-based diffusion processes. Together, diffusion and transfer convert potential techniques of production at one locus into available techniques elsewhere. It is often argued that at the present time transfer mechanisms generate a learning process between nations which allows 'latecomers' to speedily catch up with early adopters.

Technology is not simply a collection of hardware or a set of manuals, "it is these things plus people and the experience and skills they bring to the process, be they operatives, craftsmen, or managers". [2] The role of key personel has always been considered vital, from the transfer of technology into the silk and woollen manufactures of Bologna in the thirteenth century to the mechanical engineering and textile machinery transfers to America from Europe in the early nineteenth century. British industrialisation has been interpreted as predicated upon the importation of great waves of skilled peoples - from Elizabeth's employment of German and Italian experts in mining, metallurgy and glass manufacture, through the protestant migrations from the Low Countries and France to the Dutch contractors involved in the draining of the fens. Study of the transfer of Western technology into the U.S.S.R. in the twentieth century has concluded that greatest successes were gained when systems of equipment and plant were employed alongside key engineering and management personel. Blueprints do not transfer easily. [3]

Amongst economic historians, a possibly premature dismissal of the importance of science-to-technology links in specific instances (eg. latent heat and the steam engine, inorganic chemistry and the production of industrial chemicals) has led to a neglect of the entire relationship which might have existed between

[1] Although it is a major element in the present debate over the efficacy of military technologies, we do not consider here the problem of the transfer of technologies from one industry to another within the same economy. For an introduction to the area see H.B. Binswanger, W.V. Ruttan et al., *Industrial Innovation: Technology, Institutions and Development*, London, 1978.

[2] F.R. Bradbury, 'Technological Economics: Innovation, Project Management and Technology Transfer', *Interdisciplinary Science Review, 6* (1981) quote p. 151.

[3] A.C. Sutton, *Western Technology and Soviet Economic Development*, 3 vols., Stanford, 1968-73; G.D. Holliday, *Technology Transfer to the USSR 1928-1937: The Role of Western Technology in Soviet Economic Development*, Boulder, 1979.

knowledge of natural science and the production of goods. Peter Mathias and Sidney Pollard have stood out in their insistence upon the significance of transfers of knowledge and technique between nation states. [4]

The present paper concentrates upon mechanisms which emerged during the eighteenth century and which encouraged the movement of both information and discrete technologies from one nation to another. In a period prior to patents (the royal monopolies of France were not equivalent to the patents granted in Britain) and for which we do not possess comprehensive details of the costs and benefits of even major industrial projects, a descriptive and institutional account seems reasonable enough. In our last section we argue that even such a qualititive approach does not prevent some useful generalisations. At a more immediate level, any acknowledgement of the frequency of knowledge and machine transfers must cast doubt on arguments which claim that a nation's industrial breakthrough was determined by its own capacity to generate and apply appropriate and systematic knowledge. Men, manuals and machines moved.

II: Idea Merchants - The Movement of Scientific Knowledge

> "On Thursday last his Royal Highness the Prince of Wales, and the Duke of Lorraine, went to the Royal Society about Seven O'Clock and having seen several curious experiments, returned to the Ball at Court".
> (*The Universal Spectator*, 27 November, 1731).

The transfer of discrete, scientific knowledge takes place on several levels. An initial awareness of knowledge generated in another culture does not necessarily lead to its cumulative or critical assessment. Only subsequent activity in personal letters, publications, societies and lecture-demonstrations or exhibitions may be taken to indicate that initially transferred knowledge has been at least partially assimilated within a new environment. It is equally evident that such activity may involve some real transformation in the initial 'knowledge': Aided by publications, societies and the instructions of key individuals, the movement of knowledge went through just such transformations in the eighteenth century.

Legislation could not alter this. Migration was forbidden in some states, (Russia, Austria), 'disclosure' of techniques might be prohibited on pain of

[4] See in particular Peter Mathias, 'Skill and the Diffusion of Innovations from Britain in the Eighteenth Century', *Trans. Royal Historical Society XXV* (1975); Sidney Pollard, *Peaceful Conquest, The Industrialisation of Europe 1760-1970*, OUP, 1981, especially Ch. 4.

death (as with Sardinian law), exports of machinery and artizans were hindered by legislation in others (eg. England). Intellectual spies suffered imprisonment, (eg. Henry Oldenberg, F.C.L. Albert). Nevertheless, even wars produced contrary results. The Napoleonic Wars may have isolated some French scientists, but knowledge transfers between such allies as Britain and Germany actually quickened. Kant's philosophy was successfully transferred, debated and taught by Germans in Britain during 1792-97. [5] During wars enemy ships which could claim scientific intent were exempt from hazard. Sheer individual determination as well as Masonic affiliations meant that in the 60 years in which France and Britain were at war there is little evidence of a blockage in the flow of scientific information. From the 1730s the Russian intellectual masons transferred knowledge from Western Europe. In 1779 the leader of the Moscow masons, Nikolai Novikov founded the Friendly Learned Society for the Diffusion of Useful Knowledge. C.A. Helvétius, a French mason resident in Britain combined with J.J. Lalande in founding the Lodge 'Les Sciences', aimed at incorporating all scientific masons in Paris. The insidious, secret connections between internationalism, science, philosophy and politics were what so frightened Professor John Robison (1739-1805) of Edinburgh, himself returned from Russia with state honours. [6]

Harvard College abandoned its buildings, which were converted into barracks during the revolutionary wars. But the French Revolution brought to America such political refugees as the French scientists Gallatin Albert (1761-1849), P.A. Adet (1763-1834) and Du Pont de Nemours (1739- 1817) as well as the British scientific radicals Thomas Cooper (1759-1840) Thomas Henry and Joseph Priestley, (1733- 1804). The years 1774-1814 were ones of all but incessant warfare, yet a tacit pact of the idea merchants ensured that the thermometer was brought to perfection by Fahrenheit, a German working in Holland, Reaumur, a French noble employee of the state. and Celsius, a Swede. During the Seven Years war a French astronomical and survey mission passed safely to and from Tobolsk. Horace Walpole's famous claim (corroborated in the *Scots Magazine*) that the number of English people passing through Calais between 1763 and 1765 totalled 40,000 might be set against the simultaneous visits to England of such distinguished French scientists as Louis Dutens and Lalande and their

[5] F.A. Nitsch, *A General and Introductory View of Professor Kant's Principles*, London, 1796; *The English Review*, April 1796; F.W. Stokoe, *German Influence in the English Romantic Period, 1788-1818*, Cambridge, 1926.

[6] J. Robison, *Proofs of a Conspiracy Against all the Religions and Governments*, Edinburgh, 1797; R. Olson, 'The Reception of Boscovich's Ideas in Scotland', *Isis, 60* (1969); J.B. Morrell, 'Professor Robinson and Playfair and the *Theophobia Gallica:* Natural Philosophy, Religion and Politics in Edinburgh 1789-1815', *Notes and Records of the R.S. of London, 26*, (1971).

Mitre Tavern gatherings with French foreign fellows of the Royal Society and members of the Royal Society Club. When France and England were struggling over America, Joseph Priestley was strutting in Paris, 'in a bag wig, a sword and coloured clothes. So much does a commerce with the gay world induce a man to relax from the strictures of his principles'. [7] Indeed, the channels through which scientific information flowed were of a complex character, and may only be summarised here under five major sub-headings.

A. *Random Walks.* Benjamin Thomson, Count Rumford (1753-1814), is perhaps the best example of the scientist whose career was truly international. Pulled and pushed between Britain and America, the material inducements of elector Karl Theodor of Bavaria encouraged Thomson to settle there and advise the authorities on technical and military matters. On his return to London he was instrumental in the founding of the Royal Institution (1799), and this gave employment to such emergent scientists as Humphry Davy, Thomas Young, Michael Faraday and James Dewar. His most important work, the *Enquiry Concerning the Sources of Heat* was published by the Royal Society in 1798 but possibly originated when he was boring cannon in Bavaria, when it occurred to him that heat was not a fluid ('caloric') but a form of energy. His findings led to the detailed work of Robert Myer, J.P. Joule and Herman von Helmholtz. Humbler individuals who remained on the fringes of the European scientific community benefitted in a similar manner from irregular foreign influence. The London instrument maker, John Cuthbertson, gained much from his residences in Amsterdam during 1769, 1782 and 1793, his fellowship of European scientific sociėties and his cooperative work with Van Marum during 1787. Following a course of electrical experiments in Amsterdam, 'On my return to London, after delivering courses of lectures upon electricity, I once more returned to the subject of [the production of metallic oxides by electricity]'. [8]

At an institutional level, in 1764 Richard Watson could not get his course of chemical lectures at Cambridge off the ground until he had sent to Paris for a skilled laboratory assistant qualified to set up an experimental procedure. [9] At yet other levels, sons on the mercantile version of the Grand Tour reported back

[7] J. Norman to Richard Bright, 15 Sept. 1774, in Bright Family Papers, [MS Collection, Unsorted, University of Melbourne Archives].

[8] John Cuthbertson, *Practical Electricty and Galvanism,* London, 1807 quote p. 198. See also *Nicholson's Journal* (June 1792), *Philosophical Magazine* (March 1805); R.J. Forbes, (ed), *Martinus van Marum. Life and Work, I,* Haarlem, 1960; T.H. Levere, 'Friendship and Influence, Martinus van Marum, FRS', *Notes and Records of the Royal Society, 25,* (1970).

[9] L.J.M. Coleby, 'Richard Watson, Professor af Chemistry in the University of Cambridge, 1764-71', *Annals of Science* (1953).

to their merchant fathers (as did Richard Bright in 1771) incisive details about latest developments in science, military and commercial areas. [10]

The institutionalisation of science was profoundly affected by such random moves. When W.J. s'Gravesande (1688-1742) arrived in Britain as secretary to the Dutch Ambassador at the Court of George I, he met Newton, and attended the lecture courses of Desaguliers. On his return to Holland he established a Newtonian lecture course at Leyden, which may well have had some impact on the move from Cartesianism to Newtonianism in that country. Desaguliers returned the visit. When the Conde des Penaflorida returned to Spain from a tour of France in 1746, he immediately set about the erection of a *salon* for mathematical, physical and political discussion. In 1767 this became the basis for the establishment of the Sociedad Bascongada de los Amigos del Pais. Around 1681-2 Louis XIV of France learned of the operations of a small new mathematical school, which had been founded in London in 1673. There navigation, mathematics and physics were taught and followed by formal apprenticeship. Louis immediately followed suit with exact replicas in France in 1682 and 1702. On his spying tour of England, in 1698, Peter the Great of Russia learned of the very same London school, and through Dr. P. Posnikov enticed some of its graduates to Russia in 1699 and 1701. Two of these became teachers in the Moscow school of Navigation and Mathematics, modelled entirely on the London School. The influence of this small establishment may be traced in Berlin (1747) and Silesia and Serbia up into the 1780s. [11]

The relatively open society of Britain acted as an *entrepôt*, within which cultural goods were refined and re-exported. In 1741 the Prussian Ambassador in London attended the lectures of Desaguliers and immediately 'engaged almost all the foreign ministers to be of the party'. [12] The Huguenot, Dr. T. Demainbray, (1710-1802) a pupil of Desaguliers, mounted a programme of public lectures on natural and experiment philosophy during the 1750s. J.T. Desaquliers (Oxford MA 1712, FRS 1724) was himself the son of a Huguenot immigrant, curator of

[10] Letters of Richard Bright to brother and father, Feb.-Oct. 1777, in M.S., *op. cit.*, (ftn. 7).

[11] A full account and the tracing of a complex connection is in Hans *op. cit.*, (ftn. 33), pp. 213-220. For the flow of enlightenment and technology into XVIIIth century Spain see the following: J. Harrison, *An Economic History of Modern Spain*, Manchester, 1978; R. Herr, *The 19th Century Revolution in Spain*, Princeton, 1958; R. Carr, *Spain 1808-1939*, Oxford, 1966; R.J. Shafer, *The Economic Societies in the Spanish World, 1763-1821*, Syracuse, 1958; J.V. Vives, *An Economic History of Spain*, Princeton, 1969 (esp. Ch. 35) and the masterful; H. Kamen, *The War of Succession in Spain 1700-15*, London, 1969, esp. Ch. 6.

[12] W.H.G. Armytage, *The French Influence on English Education*, London 1968, quote p. 15.

the Royal Society and a freemason, (above). His public lectures on science and technology were delivered in London and eventually published in 1724 as *A Course of Mechanical and Experimental Philosophy.* The vernacular problem was solved by alternate lecturing in English, French and Latin! His lectures on the same subject in Holland in 1730 were attended by Boerhaave. By the mid-1730s the work of Boerhaave was being popularised in England. [13] Apart from a series of prizes and awards, Desaguliers received royal patronage in England and a pension of £70 per annum. His lectures of 1724 were an epitome of the European scientific enterprise and a model for the idea merchants:

> 'Whereby any one, although unskilled in mathematical sciences, may be able to understand all those phenomena of nature, which have been discovered by geometrical principles or accounted for by experiments; and mathematicians may be diverted in seeing those machines used and physical operations performed, concerning which they have read ... the experiments made at the first lecture prove the precept given at the second, and so on; things which otherwise would be merely speculative being by this means rendered objects of the senses, and better understood in a month or six weeks, than in a year's application to books only'. [14]

The early institutionalisation of science in England depended greatly on foreign residents and visitors. The gentleman of Verona, J.F. Vigani (c. 1650-1713) was teaching chemistry privately at Cambridge during 1683-1708, and publicly in 1707. His *Medulla Chemiae* was probably published first in Dantzig in 1682, but was soon translated and enlarged for distribution in England and elsewhere. James Stirling (1692-1770), educated at Glasgow and Oxford , from which he was expelled for Jacobite sympathies in 1715, studied mathematics in Venice and became acquainted with Bernoulli, Newton and Desaguliers. On his return to London in 1725 he began his lectures at the Little Tower Street Academy and the Bedford Coffee House. Dennis Chevalier de Coetlogen opened his Academy of Sciences in London during 1745. It was probably not quite as successful as his *Universal Dictionary of Arts and Sciences.* Lewis Lochiere, a Belgian exile from Austrian misrule, founded a private military and technical academy in London which taught languages, mechanics and fortification. He returned to Belgium in the liberation war of 1788 and was killed in action at Lille in 1791

[13] *The Universal Spectator and Weekly Journal,* 22 Jan. 1732; *The London Evening Post,* 21 Jan. 1735, in 2 volumes the translations of Boerhaave's *Elements of Chemistry* could be bought in numbers of 1/6d each.

[14] *A Course of Mechanical and Experimental Philosophy,* London, 1725; On these lectures see also, N. Hans, *New Trends In Education in the Eighteenth Century,* London, 1951, pp. 137-131.

B. *Publications.* Such immeasurable and often eccentric transfers of knowledge took place against a background of international publication of scientific information. The perhaps 10-fold increase in the number of scientific periodical publications during the eighteenth century has been seen by Derek de Solla Price as the real beginning to the exponential growth of scientific publication in world history (ie. the XIXth century would see a 100-fold increase in journals founded). [15] The function of the journal was to monitor and digest, and by abstraction and translation, to reduce the time-consuming process of information search. That is, scientific publications were vital to the *assimilation* of knowledge generated in other nations, (above). The dictionary or digest reported information and procedures previously available only in foreign languages, reduced the effective price of information considerably, encouraged research and further publication and acted as a forum for the examination of findings and the pursuit of priority claims. Science in general intellectual journals emerged as a platform for reportage of *observations* in the more empirical fields of natural history, geology, zoology, botany and technology. The *abstract* was vital. 60% of all XVIIIth century abstract journals in Europe were published in Germany, and through the process of review and selection provided discrete information in simplified or corrected form. [16] Good examples of books with the same function were the 3-volume version of Lorenz von Crell's 12- volume *Die neuesten Entdeckungen in der Chemie* and Christian Adelung's 6-volume *Mineralogische Belustigungen.*

The fall of Latin as a means of learned communication meant the rise of an industy of translation, from schools and lecture halls to dictionaries and reprints. Translation of important or timely foreign works often involved simplification or alteration in order 'to render natural philosophy plain to the meanest readers'. [17] On such a basis Thomas Dale translated and condensed Reganault's *Philosophical Conversations, or a New System of Physics,* and Timothy Dallowe, a former pupil of Boerhaave, translated the latter's *Elements of Chemistry,* the second volume of which boasted '227 Chimical Processes'. Peter Shaw combined with Ephraim Chambers to publish Boerhaave, a digest of Stahl's chemical course at Jena in 1730, as well as a series of miscellaneous publications of European chemical lectures from notes obtained from audience members, 'much to the annoyance of the authors'. [18]

Another type of publication was that which epitomised an existing volume and added to it related or new material from foreign sources. Dr. William Lewis

[15] For exponential growth in science indicators see Derek de Solla Price, *Little Science, Big Science,* New York, 1963.

[16] D.A. Kronick, *A History of Scientific and Technical Periodicals,* New York, 1962.

[17] *The Universal Spectator,* 22 Jan. 1732.

[18] A.E. Musson and E. Robinson, *Science and Technology in the Industrial Revolution,* Manchester 1969, quote p. 51.

(1708-1781, FRS), brought out an edition of George Wilson's *Complete Course of Chemistry* in 1746 and added to it the findings of a series of French, Dutch and German chemists. Translation itself could be slow, (as with Beckmann's *History of Inventions and Discoveries,* which took 20 years to appear in English in its full version), but individual authors, central or peripheral, speeded up the process of general communication. James Logan, the Quaker of Philadelphia, achieved and retained a European reputation mainly through his very regular and speedily published communications in the *Philosophical Transactions.* When James Aregory of Edinburgh published his *Philosophical Essays* he requested his publisher to immediately send copies to such figures as George Wilson, Joseph Priestley, Thomas Cooper, Charles Hutton, as well as to Edmund Burke and the Archbishop of Canterbury. [19]

C. *Academies and Centres of Learning.* In the middle of the XVIIIth century, half of the Fellows of the Royal Society of London were foreign nationals. By 1785 Benjamin Franklin was a member of some 20 scientific societies throughout Europe. The importance of the masonic connection with science should not be underrated, for the lodges represented an international communication network. The Society for the Encouragement of Learning, based on the Rainbow Coffee House (fl. 1735) and the Society for the Promotion of Arts at the Bedford Coffee House, London (fl. 1753) were both outposts of European freemasonry. The first President of the latter was a Grand Master. Of course, the learned institutions were more visible. Innes Smith, Lindeboom and Underwood have shown how the University of Leyden accelerated the process of information dispersal. Over 700 English-speaking students matriculated at Leyden, an institution whose science was dominated by Herman Boerhaave (1668-1738) from 1701 until his death. [20] The influence of Boerhaave in Britain was not in fact primarily through the training of medical students *per se.* It was the Newtonian popularising and public-science activity of key Leyden matriculants — Peter Shaw, Bryan Higgins (1737-1802), Henry Pemberton amongst them — which exerted a prime influence upon English culture. Shaw delivered one of the first public courses on chemistry in the country. Higgins was founder of the Society for Philosophical Experiments and Communications in London and ran a school of practical chemistry in Soho. A secondary flow connected Leyden, Edinburgh and Glasgow and London. The creative talents of John

[19] James Gregory (Edinburgh) to Cadoll (publisher), 6 Feb. 1792 in Montagu MS [MS Bodleian Library, d7].

[20] G.A. Lindeboom, *Herman Boerhaave, The Man and his Work,* London, 1968; Lindeboom, *Boerhaave and Great Britain,* Leiden, 1974; E. Ashworth Underwood, *Boerhaave's Men at Leyden and After,* Edinburgh, 1977; R.W. Innes Smith, *English-Speaking Students of Medicine at the University of Leyden,* Edinburgh, 1932.

Roebuck or William Cullen, boosted in the North by students of Leyden, flowed to the South. Edinburgh's cultural hinterland lay not in the Scottish provinces, but in London, Philadelphia or Manchester. [21] Boerhaave's influence in Scotland was institutionalised in England through the activities of Scottish teachers. Major academies for scientific training were set up by John Adams (Putney), James Anderson (Hammersmith), James Andrews (Addiscombe), Robert Bissett (Chelsea), James Forsyth (Newington) and Patrick Kelly (Finsbury).

Societies on the pheriphery acted as the terminal points of a one-way flow. Newark Academy, in Delaware, even appealed to the hard-pressed General Assembly of Scotland for financial aid to set up a library, experimental room and natural philosophy class. Scotland's answer was scathing and suggested that such requests were not so unusual: 'It were to be wished that some check were put on the frequent requests of this kind, as America, at its present flourishing state, is fully as able to enter into schemes for her own improvement and advantage, as the mother country is'. [22] Benjamin Franklin's course of electrical experiments may be traced to Adam Spencer's lectures, first delivered in the colonies at Boston in early 1744. In the spring of the same year, the Edinburgh scientist arrived in Philadelphia where had already been formed Franklin's 'Junto' for mutual improvement. The traveller William Black reported that Spencer lectured on electricity at the Library Company, State House on 29 May, and from this date began the famous 'Philadelphia Experiments' in electricty of Franklin and others, published in 1751. To the Philadelphia Academy, founded in 1749, came the English lecturer D.J. Dove in 1750, and Lewis Evans followed in 1751 and 1752. [23] Colonial institutions benefitted in other ways. Harvard's collection of journals arose from donations from the French Republic and the Quaker physician, J.C. Lettsom of London. C.W. Peale's Natural History museum and Lecturing Establishment in Philadelphia received donations from Tom Paine. [24] The attendance of R.M. Patterson at the lectures of the Scots itinerant

[21] A. Thackray, 'Scientific Networks in the Age of the American Revolution', *Nature, 262,* (1976).

[22] *The Edinburgh Advertiser,* 10 May, 1774.

[23] E.P. Oberhottzer, *Philadelphia, A History of the City and Its People, II,* Philadelphia, 1920; S. & J. Bridenbaugh, *Rebels and Gentlemen, Philadelphia in the Age of Franklin,* New York, 1962, (1st pub. 1942), esp. pp. 321-340; H. Simpson, *The Lives of Eminent Philadelphians, Now Deceased,* Philadelphia, 1859.

[24] 'Letter Books MS of C.W. Peale, 1767-1803' in 'Peale-Sellers MS Collection' [Library of American Philosophical Society, BP31], item 3 (a-c), esp. Vol. III; letter of Tom Paine at Borderton to C.W. Peale, in 'Letters of Thomas Paine 1781-1803' [Historical Society of Pennsylvania, *Autographic Collection: Paine]*; C.W. Peale, *Introduction to a Course of Lectures on Natural History, Delivered in the University of Pennsylvania, 16 Nov.*

blind Henry Moyes may well have added to his European tour in influencing his scientific lecture courses at the University of Philadelphia. [25]

Such flows between central and peripheral institutions were natural enough to nations sharing a common cultural, personal and linguistic tradition. In Russia, flows of knowledge were dictated by state policy. As Parry has summarised, the Russian Academy of Science 'was always a privileged prisoner of the sovereigns and the commissars'. [26] St. Petersburg and its Academy became Peter the Great's 'window into Europe'. As such it was staffed with foreigners, amongst whom were Europe's foremost scientists. The Swiss, Daniel Bernouilli (Academy 1725-1733) began a research programme in physics, mechanics and medicine, and wrote papers for the Academy up to 1778. Another Swiss, Leonhard Euler (Russia 1727-1741) promoted investigations into optics, astronomy, hydrodynamics and the calculus of variations. Here was strong state patronage, although poems to the Czar might gain more notice, and many more roubles, than did reports on research. [27] Such a transfer mechanism involved problems. Within the Academy itself the Russian scientists and bureaucrats favoured a schedule of technical research, ran machine shops and employed and trained craftsmen in new techinques. The German, Swiss and other Europeans promoted more theoretical researches. Outside the Academy, political change could exert strong pressures. Catherine's romance with the Englightenment was stalled by her revulsion at the French Revolution. The name of the French mathematician Condorcet, was struck off the roll of membership, and academicians were employed in censorship of the work of others rather than in creations of their own. Nevertheless, despite such breakdowns, foreign influence led to successful programmes in both *historia naturalis* and *philosophia naturalis*, was instrumental in the founding of Moscow University and, by the 1740s had produced the first of Russia's great scientists, M.V. Lomosov, a wide-ranging theorist. [28]

1799, Philadelphia, 1800; J.T. Scharf & T. Westcott, *History of Philadelphia*, Philadelphia, 1884, Vol. II, pp. 946-950. 'Peale MS Miscellany' [Historical Society of Pennsylvania: Case 15].

[25] R.M. Patterson, 'MS Notebooks, Bound Volume c 1804', containing 74pp. MS notes on Moyes lectures on Natural Philosophy, in 'Patterson Papers' [American Philosophical Society, BP 274]; MS Lecture notes of Patterson 'On the Present State of Chemical Philosophy', delivered at Philadelphia Medical Society in *ibid.; The Pennsylvanian*, 22 Sept. 1854; J.K. Kane, 'Obituary of Dr. R.M. Patterson', in *Pamphlets - Collective Biography, II*, [A.P.S.], No. 11, 1 Dec. 1854.

[26] A. Parry, *The Russian Scientist*, London, 1973, quote p. 14.

[27] *ibid.*, pp. 16-20; see the chapters on Russia in W.H.G. Armytage, *The Rise of the Technocrats, A Social History*, London, 1965.

[28] Alexander Vucinich, *Empire of Knowledge*, Berkeley and London, 1984, pp. 1-56; B.N. Menshutkin, *Russia's Lomonosov*, Princeton, 1952; V. Boss, *Newton and Russia*

D. *Mass Movement and Settlement.* Trade and war combined to displace persons. During the years 1691-1745 perhaps 40,000 Irishmen served in French armies. Trade brought large British settlements to Paris, Boulogne, Bordeaux, Montepellier and St. Petersburg as well as to the colonies. Immigration policy created large foreign settlements in many areas. The policies of the Russian government from 1762 established 'frontier' settlements of Germans, Moldavians, Bulgarians and Armenians. We know something more of one large migration — that of the French Huguenots. Perhaps 80,000 Huguenots settled in England as a result of the Revocation of the Edict of Nantes (1679-85). [29] The first result of this simultaneous migration to the Dutch United Republic (50-70,000), Germany (30,000), Geneva and Switzerland (25,000) and Ireland (5-10,000), was probably in France itself. Abroad, the Huguenots absorbed liberation ideologies and translated them back into French. The more viable organs of such transfer were the *Bibliotheque Angloise* (1717-28), the *Bibliotheque brittanique* (from 1733) and Prévost's *Pour et Contre.* [30] Eighteenth-century French freema-

1698-1796, Cambridge, Mass., 1972; M. von Lane, *History of Physics,* New York, 1950; H.M. Leicester in his introduction to *M.V. Lomonosov's Corpuscular Theory,* Cambridge, Mass., 1970, and his essay on Mendeleev in *Journal of Chemical Education, 25* (1948); P.I. Lyaschchenko, *The History of the National Economy of the U.S.S.R.*, I Moscow, 1947, Section 6; N.K. Rozhkova, (ed), *Essay on the Economic History of Russia in the First Half of the 19th,* Moscow, 1959, esp. pp. 121, 153-68; J. Scott Carver, 'A reconsideration of Eighteenth Century Russia's Contribution to European Science', *Canadian-American Slavic Studies, XIV* (1980); the essay by H. Neuschäffer in U. Liszkowski (ed), *Russland und Deutschland,* Stuttgart, 1974. Between 1755 and 1765 Lomonosov was instrumental in the publication of Moscow University's *Monthly Essays* which served to introduce to Russian intellectuals a variety of European works in natural history and economics.

[29] The Edict of Nantes, 1597, had operated so as to differentiate the two religious communities of France into separate institutions of government, education and worship. Protestants probably numbered about one million in a population of some 20m., and tended to concentrate into industry, commerce and finance. The flow into England was undoubtedly encouraged by an initial government relief grant of £64,000 which was followed by private subscriptions, mainly from London, of up to £200,000; see F. Warner, *The Silk Industry of the United Kingdom,* London, 1921.

[30] F.C. Green; *Eighteenth Century France, Six Essays,* London, 1929, esp. pp. 26-29; W.C. Scoville, 'The Huguenots and the Diffusion of Technology', *Journal of Political Economy, 60,* (1952), in parts I (294-311) and II (392-411); W. Cunningham, *Alien Immigrants to England,* London, 1897, 1969, esp. Ch. *XIV.* The first was published in Amsterdam, the second in the Hague — this should not be confused with the later Geneva publication of M.A. Pictet, C. Pictet and F.G. Maurice, (1796-1815). The major edition of the last was published from Paris during 1733-1740. A.F Prévost d'Exiles, the main editor was assisted by P.F.G. Desfontaines and C.H. Lefebvre, and supervised publication up to the 20th volume: *Biographie Universelle, 36,* Paris, (1823), pp. 64-71. The best account of the Huguenots as carriers of human capital is in Chapter 10 of W.C. Scoville,

sonry derived mainly from England. Whilst the eighteenth century witnessed far more English *visitors* to France than vice-versa, the Huguenot influence meant that Anglomaniacs were more numerous than Francophiles. Even the Edict of Tolerance of 1787 left French protestants disestablished. Until the revolution, French protestants could not hold judicial or teaching positions and so, as with the English dissenters, the educated amongst them tended to seek higher education or advancement by at least temporary residence elsewhere. Again, it was in England that the Huguenots were most readily assimilated. By 1731 there were only 20 Huguenot churches in England, by 1782 only 11. During the Napoleonic wars deliberate anglification of names and affiliations was common. The revolution witnessed a new surge of French émigrés, arriving not only in London but at Staines, Petersham, Richmond and Norfolk. In one week during 1792 1,300 French people landed at Eastbourne. According to the *St. James Chronicle* of 13 September 1792, by that year there were over 40,000 persons of French *birth* resident in England. In London, Spitalfields was probably the last area of settlement to maintain any real Huguenot cultural identity. Absorbed as a group, the contribution of the Huguenots to the transfer of ideas and information is probably impossible to determine. Certainly, intellectual gatherings and influences are identifiable. In Fleet Street, London, the Rainbow Coffee House and bookstore (see above) served as a forum for Huguenot intellectuals. Therein met De Moivre (mathematician FRS), Halley, Newton, and De Saint-Hyacinthe (translater of *Robinson Crusoe*). John Chamberlayne and Ephraim Chambers (both FRS' and Huguenots) translated the papers of the Academie into English and the second published his famous encyclopedia in English in 1728.[31] Of all emigrant groups into Engalnd (cf. the 1800 members of Dutch churches in London) the French Huguenots and their descendents appear to have been particularly involved in the spreading of scientific knowledge.[32]

E. *The State.* We have already noted several instances of state involvement in the transfer and diffusion of scientific knowledge. England was the nation of least *direct* involvement. The activity of British governments of the eighteenth century in stimulating trade, navigation and colonial expansion, together with successful foreign wars and measures of social control at home were sufficient inducements to controlled social change, *relative* political stability and a resulting dispersal of scientific knowledge between regions and social groups. How-

The Persecution of the Huguenots and French Economic Development, 1680-1720, Berkeley, 1960.

[31] Scoville & Cunningham, *ibid.*, and C. Weiss, *History of the French Protestant Refugees,* London, 1854; *Biographie Universelle, 39,* Paris, (1825), pp. 595-598.

[32] D. Ormrod, *The Dutch in London, 1550-1800,* London, 1973.

ever, even in England pensions and rewards could be gained through proven achievements which related to the needs of a mercantile state. Early in the century Humphrey Ditton, master of the New Mathematical School at Christ'Hospital (see above), and William Whiston, addressed a Bill to the House of Commons suggesting the establishment of a prize for the successful invention of an instrument or technique for measuring longitude at sea. As a result an Act of Parliament in mid-1714 offered a reward of up to £20,000 for the solution. [33] The subsequent attempts to gain this considerable sum involved individuals such as Ditton and Whiston in England, Leibnitz, Christoph Semler (1669-1740) of Halle University, Christoph Eberhard and others. Eberhard, on his way to England, met Peter the Great in Amsterdam in 1717. After offering Semler's invention to Peter (!), Eberhard was invited to Russia, where he remained until 1730 and was employed in shipbuilding and navigation. Only in 1772 did John Harrison (1693-1776), son of a carpenter, succeed in obtaining the whole sum by vote of Parliament.

England's innermost cultural-colonies, Scotland and Ireland, represent an intermediate mode of encouragment. Here the state itself did little to interfere *directly* in scientific activity, and this function was taken over by its representatives amongst the upper classes and bureaucrats. [34] A philosophy of 'improvement' was distilled in an effort to encourage the diffusion and application of both existing and transferred knowledge. *Hibernicus public* valued knowledge as, potentially, a powerful public good: 'Some of our neighbours, the *Hollanders* in particular, have made learning a Branch of Commerce. Vast sums of money are yearly drawn into the Provinces, not for the purchase of their own learning only, but for mere manufacturing that of their neighbours'. [35] At a later date the Dublin Society for the Relief of Protestant Strangers took on an even more specific 'improvement' ethos. One of the funcions of this society was to halt the flow of protestants, French Huguenots among them, from Ireland to the colonies or even Prussia and Russia. Settlement in Ireland must be achieved, 'where they

[33] Hans, *op. cit.*, (ftn. 14), pp. 217-18.

[34] For the economic and locational forces behind the dominance of elitest improvement movements in Scotland see C.R. Fay, *Adam Smith and the Scotland of his Day*, Cambridge, 1956; Chapter IX of R.H. Campbell, *Scotland Since 1707*, Oxford, 1965, *Idem.*, 'The Industrial Revolution, A Revision Article', *Scottish Historical Review 46* (1968), N.T. Phillipson and R. Mitchison (eds), *Scotland in the Age of Improvement*, Edinburgh, 1970; N.T. Phillipson, 'Culture and Society in the 18th Century Province: The Case of Edinburgh and the Scottish Enlightenment', in L. Stone (ed), *The University in Society*, Princeton, 1975; C. Smout, 'Centre and Periphery in History: With Some Thoughts on Scotland as a Case Study', *Journal of Common Market Studies, 18 (1980).*

[35] *Dublin Weekly Journal*, 20 Aug. 1726.

might expect to be best used and most encouraged to carry out their Respective Trades and manufactures'.[36]

At the other extreme of the English model of 'science in culture' was direct state tutelage in such relatively economically backward, despotic and mercantile nations as Russia and several of the German states. Of the total budget of a hard-pressed state, the Ministry of Public Instruction in Russia spent 1.4% in 1795, 2.1% in 1805 and 2.1% in 1825. Other Ministries supported such instruments of scientific and technical modernisation as the Institute of Mining (1773), the Military and Medical Academy (1799) and the Forestry Institute (1803). In perfect contrast to England, in Russia the University Statutes of 1787 promoted meritocracy and a formal link with entrance qualifications gained in the newly-rejuvenated Major Schools. Although fees were demanded from the wealthy, youths from serf families could gain free entrance upon examination success. At the Universities students intended for law or medicine had to first pass through the philosophical (scientific) faculties. At the turn of the century the impact of the French revolution and the Condorcet scheme for educational reform (so abhorred by Catherine) was effected in the foundation of new Institutes and Lycées. Separate institutions were formed for technical instruction, although natural science subjects began to be taught at even the primary level of education. By 1826 nearly 30% of all pupils in the Russian *gymnasia* were from the families of the 'middle and lower orders'.[37]

III. Change Agents: The Movement of Technical Knowledge

"Russia is a
European Power".
[Catherine II of Russia, 1766]

Although the industrial revolution occurrred in England first and was strongly associated with the application of a host of new technologies in agriculture, industry and transport, many foremost inventions of the eighteenth century in fact originated in Europe. The later 'epoch making' inventions of the Jacquard loom, the Seguin multitubular locomotive boiler and the Heilmann comb were

[36] *The Dublin Gazette*, 3 March 1753.

[37] N. Hans, *History of Russian Educational Policy 1701-1917*, New York, 1964, 1931. For wider aspects of bureaucratic involvement in transfers of European knowledge to Russia see P.H. Clendenning 'Eighteenth Century Russian Translations of Western Economic Works', *Journal of Eur. Econ. History, 1* (1972) and his 'The Economic Awakening of Russia in the Eighteenth Century', *ibid 14* (1985).

continental inventions.[38] From Europe rather than Britain came major technical breakthroughs in paper-making machinery, cylinder printing presses, mechanical typesetting and stereotyping, as well as in agriculture, eg. development of crop rotations and seed drills. At the same time, much of the technology *applied* in England originated from or derived from the innovative activity of Europeans, either in their own nations or settled within Britain. As with scientific knowledge, it was the transfer of techniques which ensured that industrialisation did not necessarily come to the nation with most creative flair.

War and restrictive legislation, even in combination, could not inhibit the movement of techniques across national frontiers. Bourbon rulers exerted hegemony over the Spanish economy throughout the early years of the XVIIIth century The majority of the 65,000 French settlers in Spain were artizans and mechanics, and were particularly congregated into the urban areas. Although the authorities discouraged French entrepreneurs and technicians from introducing new industries into Spain, and although they constructed a sophisticated system of controls, this did not halt a flow of expertise into the nation's woollen, glass, iron, gunpowder, paper and silk industries. In Britain, the formal restrictions on movement of skilled workers were lifted only in 1825, whilst those on the export of machinery continued in force until 1842. These did not prevent John Kay, frustrated by the English patent system, from moving himself and his spinning machinery to France, where he commenced business by utilising machinery already smuggled out of England by John Holker.[39] Between 1763 and 1765 an agent of Johann Cahman, an ironfounder of Gothenburg, persuaded two skilled employees of Roebuck and Garbett at the famous Carron works in Scotland to leave for Germany. The law prevented both from leaving, and the agent was arrested. However, in 1765 Samuel Garbett reported to the Home Office that yet another of his ironworkers had indeed reached Gothenburg.[40] In 1782 Baden was fined £500 and in 1792 Charles Albert was imprisoned and fined £500 for recruiting skilled labour in England. James Cockerill came up against the authorities when he returned to England in 1802 in order to smuggle both machines and operatives out of Hull. Although Albert was caught, a little later (1796) he had established a spinning mill run with the help of skilled artizans from England, and by 1803 had erected a textile machinery plant in Paris! Neither legislation nor war had prevented the movement of technique.

[38] W.O Henderson, *Britain and Industrial Europe 1750-1870*, Leicester, 1972, esp. pp. 1-9.

[39] D.N.B. (John Kay). See also D.J. Jeremy, 'Damming the Flood: British Government Efforts to Check the Outflow of Technicians and Machinery 1780-1830', *Bus. Hist, Rev. 5* (1977).

[40] Henderson, *op. cit.*, pp. 5-6.

War could obviously exert negative impacts upon the *internal* diffusion mechanisms: it might well be argued that the costs and devastations of the Napoleonic wars destroyed normal market relations in France, channeled capital and initiative into non-industrial pursuits, and thereby put Britain ahead of France in the race towards the diffusion of European best-practice. On the other hand, the effectiveness of the Continental System, by which many products were blocked off, encouraged the movement of Swiss handspinners and machine weavers into Alsace to satisfy the demands of Mulhouse for skilled workers. The French wars led to the French take-over of areas of Germany during the 1790s, a first effect of which was a loosening of guild control over industry, a reduction of internal customs duties and an increase in the size of the market for local products, all of which encouraged entrepreneurial activity. But in addition, industrialists in areas such as Aachen were yet able to introduce British mechinery during the 1800s (eg. power looms). As Trebilcock observes, despite war, 'Cockerill in Aachen, like Wilkinson and Baildon in Silesia, was a citizen of an industrial world, moving easily between the manufacturing centres scattered across Europe'. [41] The Napoleonic Wars did not hinder Casper Voght (Germany) or J.C. Fischer (Switzerland) in their investigations of British techniques in agriculture and metallurgy.

Such features of the transfer process may be pushed well back into the century. Just months prior to the French-American Treaty of Commerce and Alliance of February 1778, which made explicit French covert assistence to the Americans in their war against England, at a time when the Comte de Vergennes was declaring openly that England is the natural enemy of France, 'greedy, ambitions, unjust and false', the English businessman and merchant Richard Bright wrote to a colleague in England that, 'at the request of the Count de Clonard, Mr. Andrew French's father-in-law, I have given him a letter of introduction to you, he is lately become concerned in a Glass Bottle Manufactury in this neighbourhood [Paris], and wants some information, I believe respecting the Potts they make use of with us. I conceived this to be no secret'. [42] More generally, the fear instilled by even the prospect of war had often served to provoke a policy of technology transfer. In Russia during 1698-1710, the insecurity of supplies from the enemy, Sweden, and the need for war materials, induced a policy of industrial development in the Urals which owed enormously to European technologies. [43]

[41] C. Trebilcock, *The Industrialization of the Continental Powers, 1780-1914*, London, 1981, p. 31.

[42] R. Bright to Lowbridge Bright, from Paris, 7 Sept, 1777, Bright papers MS [Melbourne University Archives, *op. cit.*, ftn. 7: Loose Letters, miscellaneous].

[43] A. Kahan, 'Entrepreneurship in the Early Development of Iron Manufacturing in

Of course, war and competition prompted some retaliation. In 1798 the proprietors of the Wick Iron Company, Ireland, alerted William Wilberforce to the state of the iron industry and the need for government encouragement:

> 'Let us look at the relative situation of our Iron Trade compared with that of other states. An Apostate Englishman has emigrated to Russia and there constructed large foundries, which supply her with the best ordnance, such as we used to export thither: He has also lately established a manufactury for metal buttons and Birmingham Wares, in which more than 300 hands are already employed. Russia is likewise supplying America with a variety of heavy articles in the Ironway, and has in a great degree taken from our trade to Portugal in iron hoops, which till now has been exclusively our own. Sweden is increasing her manufactures of Iron Wares. Holland, Liege, and other parts of Germany are underselling us in divers articles. America too is extending her Iron Manufactures, and industriously seducing our artificers to emigrate and work *against us*'. [44]

But the trade in technologies could not be halted by legislation. It is true that Samuel Slater, who had moved to Rhode Island in 1790 after employment at the mills of Arkwright and Strutt, could not get blueprints or models of the technologies out of the nation. But he solved the problem, as did so many others, by carrying precise information in his head as mental capital, quickly utilised for the establishment of mechanical spinning in New England. In fact, in America a variety of methods were adopted in order to abstract concise technical detail. British manuals were imported wholesale. From the 1790s the American *Repository of Arts* reported on all major British patent specifications in textiles and related fields. Skilled textile operatives carried knowledge and experience with them. The number of British textile operatives emigrating to America escalated from 422 in 1773-75 to 631 in 1809-13 and 2632 in 1824-31. [45] Key Britishers established entire manufacturing enterprises - J. and A. Schofield in woollens, J. Nancarrow and James Smallwood in steam engines, W. Weston and B.H. Latrobe in engineering. Americans such as Thomas Gilpin, Francis Lowell, G.E. Sellers, visited England, learned much and hired skilled workers to return with them. Emigré's diffused modern technical knowledge within America, Thomas Cooper translated Berthollet for his *A Practical treatise on Dyeing*, J.T. Coxe turned to P.M. Orfillo for his *Practical Chemistry*. Although the Americans also

Russia', *Economic Development & Cultural Change, 10*, (1961-62); Olga Crisp, *Studies in the Russian Economy Before 1914*, London, 1976, Chapter 2.

[44] 'Wick Iron Company, — Summary of the Iron Trade, 1798', pp. 2-3, in *Bright Papers* (*op. cit.*, ftn. 7).

[45] D.J. Jeremy, *Transatlantic Industrial Revolution: The Diffusion of Textile Technologies Between Britain and America 1790-1830*, Oxford, 1981, pp. 264-66.

learned from the French, it was the neo-colonial relationship, strong in trade, which determined the larger flow of information and machinery. [46]

Other transfers were spasmodic and dependent upon the whimsy of individuals. Another Carron employee, Thomas Lewis, arrived in Sweden and in 1769 secured permission to establish a British-style iron foundry at Stockholm, the origin of Bergsund's machine-building enterprise. Thirty years later yet another Carron man, John Baildon, built coke - blast furnaces at Gleiwitz. William Douglas was brought to France by Chaptal, Napoleon's Minister of the Interior, and established the manufacture of carding and spinning machinery in Paris. In the Belgian provinces of France, William Cockerill and James Hodson established textile machinery plants at the turn of the century. By 1807 Cockerill and his sons were at Liège manufacturing carding machinery, spinning machinery and mechanical looms for the woollen industry, only about half of which were sold in France itself. Whilst the latter flows were mainly from Britain, there were many exceptions. The textile centres of Bohemia, Moravia and Lower Austria obtained their machinery from Britain and benefitted by exploitation of markets left unsatisfied during Napoleon's ascendancy, but Italy's new technology came from France, the Guadalajara Woollen Mill in Spain was founded on a combination of English, Irish, French and Dutch artizans, and Mathias has noted that 'Estonia was largely a technological and business dependency of German groups'. [47] It is obvious that the transfer of technique was often a random affair, similar to the movement of scientific knowledge. Unlike science, the movement of technology was also bound up with the expansion of trade and the penetration of foreign capital and financial groups into new, developing regions.

A. *Science and Technology*. Musson and Robinson have convincingly shown that, in the case of Britain during the whole of the XVIIIth century, there is little to be gained from an artificial separation of interests in natural science from interests in technique — the same publications and the same congeries were involved. [48] In Britain, the Lunar Society of Birmingham has become perhaps the best known of the societies whose research and discussion embraced science and technology and whose personal connections were international in scope. Priestley was first known in France as the discoverer of a commercial method of making soda water, rather than as a 'pure' chemist. Important technical pro-

[46] B, Hindle, 'British versus Fench Influence on Technology in the Early United States', *International Congress of the History of Science, 11, Proceedings*, Paris, 1965, parts 4-6, pp. 49-53.

[47] Peter Mathias, *The Transformation of England*, London, 1979, p. 22.

[48] Throughout Chapters 1 and 2 especially of *op. cit.*, (ftn. 18) and Musson's introduction to A.E. Musson (ed), *Science and Technology in the eighteenth Century*, London, 1972.

grammes, such as that of another Lunar Society and Philosophical Society member, Josiah Wedgwood, were based on the application of scientific method if not new scientific knowledge. In the manufacture of pottery, the maintenance and monitoring of a crucial temperature in the kiln was essential, and solved by Wedgewood's invention of a pyrometer, which he sold as a standardised piece of equipment to yet other producers.

Under various auspices scientists with specific knowledge of industrial processes were involved in the establishment of new technologies in new environments, and several entrepreneurs were trained in science in other nations. Ambrose G. Hanckwitz (1660-1741, FRS) learned of a method of manufacturing phosphorous from urine whilst assistant to the scientist Robert Boyle. In 1710 he established his own business along those lines at the same time as he was chemical analyst to the Royal Society. His son, Boyle Godfrey lectured on chemistry at Paris in the 1730s. The scientist and Huguenot-descendant J.T. Desaguiliers built steam engines along the lines of those proposed earlier by Papin and Savery, at least one of which was on order from the Czar of Russia. Another Huguenot intellectual, Lewis Paul, invented in England the roller-spring. Yet another, Charles Lebelye was the engineer of the first Westminister Bridge and introduced the *caisson* method for building underwater foundations. In America, an exception to the British connection was Irenée E. du Pont who had studied under Lavoisier and continued to maintain links with French science when establishing his manufacturies for gunpowder, textiles and tanning in America. During the mid-1790s the chemist Bryan Higgins was invited by the Jamaican House of Assembly to go there in order to improve their methods of sugar and rum production for which he was paid a salary of over £ 100 per annum. The French scientist de Gensanne supervised the erection of furnaces at Hayange to smelt iron with coke in 1723. Recent technological breakthroughs were reported in scientific journals almost as frequently as in specific, industrial-oriented outlets. The first international publication of R.J. Eliot's invention for smelting iron from black magnetic sand, demonstrated at Killingworth, Connecticut, was in the *Transactions* of the Royal Society of London in 1762. This gained him the gold medal of the Royal Society of Arts. Entrepreneurs seeking new methods could be profoundly influenced by the availablity of special scientific knowledge. The chemical engineer, John Roebuck gained such information in lecture courses at Edinbourgh and Leyden. The knowledge gained by John Keir when translating P.J.Macquer's *Dictionary of Chemistry* inspired him to set up his alkili works at Dudley. [49] It is obvious that any historical analysis of the industrialisation process of the eighteenth century which divorces science and technology is fraught with danger. An artizanal inventor of 1750

[49] On Keir and such scientific influence see Musson and Robinson, *ibid.*, pp. 31, 58, 87-8, 96, 121-7, 142-3 *passim.*

or 1790 who picked up a scientific journal also picked up explicit knowledge of new techniques.

B. *Britain as Receptor.* Although we may quite accurately depict *late* eighteenth century Britain as possessed of a vigorous and developing scientific-technical culture, we must acknowledge that this was itself a partial product of earlier transfers into the nation, several examples of which have already been provided. This is true for technology also. Similarly, although the later eighteenth century flow of technology was mainly from Britain to other nations, this owed much to an earlier phase of technology borrowing from Europe. The English iron industry benefitted from the Swedish tour of agents of such leading iron masters as Ambrose Crowley and Samuel Garbett. There were dramatic exceptions — the Newcomen engine of 1712 was in use in Hungary in 1721, in Paris in 1726, in Belgium, Austria and Sweden by 1729, a process of transfer owing nothing to formal licencing agreements and everything to British mechanics. [50] But, on balance, the early years of the century were characterised by an open two-way flow of specific techniques, with Britain gaining disproportionately from the permanent settlement of French Huguenot, Dutch and German migrants.

A German born in England, Benjamin Huntsman, (1704-76) first produced pure and hard steel in Sheffield. The Dutch were essential to the improvement of British drainage and canal systems, the French in civil engineering. M.I. Brunel was a French refugee, and Manchester's engineering community included the Swiss, J.G. Bodmer and, at a later date, the Americans J.C. Dyer and Jacob Perkins. Scientists such as Desaguliers kept in constant touch with *provincial* French academies and translated the new works of French engineers. From the seventeenth century, Germans settled at Keswick and elsewhere in order to mine or process copper and other minerals. In fact, the London-based German merchants of the 'Steelyard' acted as a local headquarters for the British interests of the Hanseatic League. Such connections carried not only specific knowledge, but were also important in the spreading of foreign language sources, as well as in the founding or running of institutions (eg. the German mathematician John Müller at Woolwich Academy from 1741). By 1724 the Lombe silk factory near Derby was established, and in the next year its promoters were boasting that 'A girl of 11 years of age does the work of 33 persons'. [51] As Wilson puts it, the techinique used had been 'purloined' from Italy. [52] Here is evidence of direct transfer of a measurably superior European technology. John Lombe, a Norwich silk weaver, worked for a time in an Italian silk throwing mill. Smuggling out exact drawings of machinery, Lombe obtained a patent in 1718

[50] Mathias, *op. cit.*, pp. 29-30.

[51] *Dublin Weekly Journal*, 18 Dec. 1725.

[52] C. Wilson, *England's Apprenticeship 1603-1763*, London, 1965, p. 299.

and with the combined help of the Derby engineer George Sorocold and the financial assistance of metropolitan businessmen, set up the new works on the river Derwent. Very soon his silk was underselling the imported Italian *organzine* by 30%. [53]

The total *economic* impact of such transfers on the British economy in the period is impossible to *measure*, for the data required to describe the *technological* superiority of such transfer is unobtainable. Perhaps of more importance was the long-term effect of early transfers upon the establishment of a widespread , interlocking culture of science and technology in Britain, firmly established by 1780. This hybrid culture was the immediate backdrop for the technological changes associated with the industrial revolution.

C. *Transfer Enterprise — France and Russia.* With their emphases on commercial reform and industrial development, the Ministries of Turgot and Calonne from the 1770s dictated the pattern of technological transfer into France. From the introduction of British-style enclosures, drainage and land clearance schemes, to the erection of the Creusot ironworks, influence from across the channel emerged as the dominant force, and was associated with special inducements. Leading agents of change in these years included John Milne from Manchester, who introduced the Arkwright frame, William Wilkinson, brother of the famous iron master John Wilkinson and former pupil of Priestley at Warrington, who set up the Le Creusot Iron Works and later smelted lead ore with coke in Silesia at Frederick II of Prussia's canon foundry, John Holker the Lancashire radical, who introduced the spinning jenny into Normandy and travelled through France as Inspector General of factories, and Michael Alcock, who established metalworks at Roanne and elsewhere.

The movement of such key individuals was effected in the visits of leading French businessmen or bureaucrats to England. Gabriel Jars and Marchant de la Houlière had both visited England whilst considering the establishment of coke smelting in France. Houlière brought back Wilkinson with him. The ironmaster Ignace de Wendel, who first succeeded with the coke smelt at Le Creusot, visited England under government auspices. Such visits were extensive and

[53] *Ibid.*, pp. 299-300; W.H.B. Court, *The Rise of the Midland Industries*, Oxford, 1938. For the best account of the Lombes and their silk factory see D. Lardner, *Cabinet Cyclopaedia: A Treatise on Silk Manufacture*, London, 1831; G.R. Porter, *Treatise on the Origin, Progressive Improvement and Present State of the Silk Manufacture* , London, 1831; G. Unwin, *Samuel Oldknow and the Arkwrights*, Manchester, 1924; W. English, 'The Texile Industry: Silk Production and Manufacture 1750-1900' in C. Singer et al, (eds), *A History of Technology*, Oxford, 1958; W.H. Chaloner, *People and Industries*, London, 1963; S.D. Chapman, 'The Textile Factory Before Arkwright: A Typology of Factory Development', *Business History Review, XLVIII*, (1974).

exploratory, part of a general learning process rather than a specific search; Jars inspected English collieries, tramways, Newcomen engines, Huntsman's process (above), the blast furnaces of Carron Co. (above) and furnaces at Clifton. Jars, a pratical mineralogist as well as an academician, spent much of the period 1757-1766 touring mines in Saxony, Austria, Bohemia, Hungary, Norway and Sweden, as well as Britain. There was in addition much smuggling of machinery and blueprints, particularly in the case of the Newcomen-Watt pumping engines, coke furnaces, and mule jennies. Pollard notes that the first generation of French engineering firms was represented by men such as Constantin Perier, de Wendel and Albert (above), all of whom were trained or influenced in Britain. [54]

Transfers into French textiles took the form of a fairly integrated, government-instigated development effort. [55] From 1747 John Kay was employed by the French woollen manufacturer Daniel Scalogne — who had previously inspected textile enterprises in England — in making shuttles and teaching local weavers. In 1749 Kay was awarded a government grant of 300 livres and a salary of 2500 livres per annum to visit Normandy textile centres and instruct weavers in the use of the flyshuttle. John Holker gained government assistance in the form of expenses, salary, subsidies and the granting of a royal 'privilege' (patent of monopoly) when he established a factory at Rouen, mostly directed to the weaving of woollen and cotton materials using British machinery and artizanal spinning skills. Of 86 skilled artizan employees at the Rouen works in 1754, the most important positions were held by 20 skilled British workers, who worked with the aid of a full time interpreter. The Rouen factory may be characterised as a development project: 1. Its technology and mode of organization was directly emulated and established in other centres — Vernon, Elbeuf and Pont de l'Arche; 2. A number of French workers received specific, formal education at the Rouen factory and later became foremen of works at other places; 3. Several British employees of Rouen were later builders of textile machinery in France; 4. Some British employees set up their own independent factories elsewhere — Danuel Hall at Sens, James Morris at Rouen; 5. French employees copied this — Piere Fouguier at Bernay and Thomas Leclerc at Bourges; 6. The original Rouen factory diversified into *other* areas of production. For example, in 1763 Holker ran a cotton velveteen branch and his cousin, James Morris, organised a calendering establishment which received royal privilege in 1766. 7. Holker offered advice to the French authorities on how to avoid British restrictions upon machine exporting (by using Rotterdam as an entrepôt) and stimulated recruitment of skilled workers from Scotland and from Irish regiments stationed in France (see above). When he was appointed Inspector General of Factories his

[54] S. Pollard, *Peaceful Conquest*, Oxford, 1981, p. 146; *Biographie Universelle*, 21, Paris, (1818), p. 415.

[55] A good account is in Henderson, *op. cit.*, (ftn. 38), Chapter 2.

salary was boosted to 8000 livres per annum!; 8. At a different level of diffusion, as Inspector, Holker obtained government subsidies for *other* British entrepreneurial ventures at Bourges, Lyons, Amiens and elsewhere, and enticed British technicians to come to France to teach the use of the Jenny and the manufacture of spinning machinery. In addition, he encouraged the use of British skills in the establishment of factories for muslin, cloth, cotton, iron, armament, glassware and chemical production; 9. Lastly, there was a continuity in a second-generation effect. John Holker jun. (1745-1822), after employment by the French government in England (inspecting Hargreaves' and Arkwright's processes) became the French Consul General at Philadelphia. His son (J.L. Holker, 1770-1844) developed a procedure for continuous combustion in the manufacture of vitriol which he commenced on a commercial scale at Rouen and Paris. This example, derived entirely from the brilliant detective work of Henderson, suggests that the successful transfer of technologies involved a complete 'package' of sub-elements — entrepreneurship, specific skills, government finance and patronage stimulated by demand. When such conditions were satisfied, initially transferred technology could spread not only from one location to another within a nation but from one project or industry to another.

In Russia, the role of the government was of even greater importance in setting up the chain of circumstances required by the transfer process. When in 1765 Catherine established the Institution of the Free Economic Society for the Encouraging of Agriculture and Commercial Husbandry, it was neither free nor particularly encouraging. Perhaps inadvertently, the enlightened Empress had brought together a group of individuals whose agenda emphasised the tremendous relative economic backwardness of Russia. Population grew from around 23 million to 37 million, resulting from both natural increase and a process of imperial expansion (eg. into the Ukraine and Lithuania). With massive shared borderlands, a small revenue base and an urban population of only 4%, the Russian state was forced to confront the problems of the contradiction between its great political ambitions and economic reality. Regional markets, divorced by spatial, topographic and transportation features [56] were in the main satisfied by *kustar* (rural-based) industrial producers working mainly in the winter months and employing simple hand tools. It was certain fear of Poland and Sweden which stimulated the employment of key foreign nationals in the leading sectors of the economy, especially in the heavy area of iron manufacture. There existed perhaps 50 foreign manufactures of some significance in all Russia during the seventeenth century. [57] By 1730 there were no enterprises in the mining regions

[56] For features of Russian backwardness see W.L. Blackwell, *The Beginnings of Russian Industrialisation 1800-60*, Princeton, 1968.

[57] Crisp. *op. cit.*, (ftn, 43), p. 58.

of the Urals which did not owe something to foreign enterprise, particularly that of Scandinavian or German origin. [58]

The development of foreign enterprise was associated with the emergence of Russian gentry entrepreneurship from the 1740s, with cheap labour in the form of either *adscribed* or *possessional* peasants, and the increased demands in Britain for the products of the nation's iron fields. The Urals became the principal source of British iron during the mid-eighteenth century and possibly the greatest single producer of iron in the world. External trade provided an inflow of foreign commercial capital which could supply the government-oriented modernising industrial sector. In terms of simple growth figures, it was to be the military-oriented heavy sector which most succeeded — pig iron production per annum multiplied 30-fold, cast iron production outgrew even this, but the number of iron producing enterprises increased by perhaps only 3 times i.e. in the heavy sector of the economy there is some evidence of increased concentration of production. Although there were some 200,000 factory workers in Russia by 1800, modern industry was essentially *enclavist.* The *kustarni* industries remained mainly untouched, and even in a city such as Moscow, a centre of transferred technology, peasants and serfs composed some two-thirds of the total population as late as the 1790s.

The foreign element in all this was of great significance. Most of the nineteenth century cotton finishing and printing factories in Moscow of the nineteenth century had been established by foreigners during the eighteenth century. Of 104 enterprises registered by the Office of Manufacture in St. Petersburg in 1775, 46 were foreign-owned (mostly French and British), and this figure excluded many foreign firms unregistered. [59] Twenty years later the number of factories in that city which were foreign had fallen to some 20%. [60]

Because of the strategic and enclavist nature of the state-dominated sectors, the activities of foreigners were at once more *induced* and more *restricted* than in the nations of Western Europe. As elsewhere, earlier activities were spasmodic. As early as 1632 a Dutchman established an ironworks and two years later glass-making was started by a visiting Swede. But such instances were *ad hoc* and mainly of very limited impact. It was only in the mid-XVIIIth century that transfer mechanisms became regularised and divorced from the uncontrolled activities of foreign commercial capital. When the Dane, Christian Lieman established a cotton printing factory it was in association with Russian capital. Müller's silk factory of 1758 was financed and maintained by Count S.P. Yaguzhinsky, who also arranged for a supply of serf labour and received an increase in tariff protec-

[58] Kahan, *op. cit.*, (ftn. 43).

[59] R.P. Bartlett, *Human Capital, The Settlement of Foreigners in Russia 1762-1804*, Cambridge, 1979, p. 164 forward.

[60] Blackwell and Bartlett extensively.

tion. In 1764 the Swiss, J.P. Ador contracted with the government an 8-year loan of 12,000 roubles to finance the engagement of foreign workers, the grant of a state-owned building — which by 1774 had cost the government nearly 13,000 roubles in upkeep — and duty-free importation of equipment into Russia to the value of 3000 roubles. Moreover, as part of the training — learning process, the state financed the employment of Russian apprentices at the works. This support package meant that Ador's subsequent problems were not technical ones, but related to the vagaries of the luxury market. In 1765 two French merchants contracted with the Russian College of Mines to establish a manufactury for the production of 'tin and from it all sorts of cooking-ware, the galvanising of sheet-iron, the manufacture of steel, scythes, sickles and thimbles'. Supplied with labour and metal at below the market prices, the state also granted a 20,000 rouble loan over a 109-year period to set up the enterprise on Lake Onega. During the year 1765-66 the firm recruited some 100 French families in order to satisfy the need for specific craftsmanship. Operating from 1768, by 1773 the firm was processing steel and had become involved with saw-mills. One of the partners, P. Barral, claimed that the total establishment and early running costs had reached some 500,000 livres (i.e. approximately five times the government direct grant) and was supplyng tin at a far greater level than was required to satisfy internal demand. [61]

Perhaps the best illustration of the Russian model of transfer was the industry and machinery partnerships of Charles Baird, Charles Gasgoyne and Francis Morgan during the 1790s. Baird, yet another Carron-trained expert (see above) was invited to Russia in 1786 in order to establish an ironfoundry and machine works. [62] In 1790 in partnership with Gasgoyne and Morgan, he began an enterprise which by the turn of the century was producing at an annual value of around 130-140,000 roubles. By 1825 the Baird works had constructed over 140 steam engines, and Baird himself had diversified into advising the government on military, civil engineering and machine construction elsewhere in Russia. Apart from direct orders, the State aided the enterprise considerably. Of 133 employees in the machine works at the turn of the century, 67 were state-paid apprentices. In 1804 the College of Mines decided in Baird's favour when he applied to purchase peasants for factory labour. In 1806 Baird obtained permission to employ up to 100 Russian workers from other existing *manufacturing* enterprises as 5-years apprentices at his works. With his partners Baird took over the leadership of the metallurgy and machine-construction enterprise of

[61] Bartlett, *ibid.*, pp. 171-73.

[62] *Ibid.*, pp. 178-9 Henderson, *op. cit.* (ftn. 58), pp. 216-218; S.J. Tomkireff, 'The Empress Catherine and Mathew Boulton', *Times Literary Supplement*, 22 Dec. 1950.

the nation. When his son, Francis, was ennobled by the Russian government in 1852 he employed no less than 442 Russian peasants. [63]

D. *Transfer and the State.* As with science, we note an approximate relationship between degrees of relative economic backwardness and fear of foreign conquest and degrees of penetration by the state in the transfer of technologies. Throughout the eighteenth century, most of the 'factories' into which modern technologies were settled were in areas closest to State interests — dockyards, arsenals, armaments, metallurgy and mining and transport systems. Again, Russia is the extreme example. Here the state was perhaps primarily interested in the producion of foodstuffs and clothing for self-sufficiency in times of war. Sericulture, viticulture and sheep breeding are all examples of sectors requiring technical investigation into the *acclimatisation* of natural products in new environments, necessary in order to reduce import dependency. In 1764 the Regulations governing settlement of the Volga region concentrated upon increased colonial immigration from Germany and elsewhere in order to improve agricultural technique. In 1775 the Chancelery of Guardianship promoted sericulture in the Volga and employed the expertise of foreigners. Such activity became more centralised in 1797 with the establishment of the Board of State Economy and the College of Manufactures. Under the new system foreigners (Greeks, Armenians, Georgians and Germans) and Russians received land grants for innovative projects. In viticulture, Potemkin recruited a Frenchman, who served as Inspector des Vignobles during 1779-84. The Board of State Economy decided on the formation of three state training schools, the supply of teachers for which was eventually solved by recourse to France and Germany. [64]

Under Catherine the state coffers even paid for the travel and removal expenses of foreign entrepreneurs and technical employees. The vetting process was centred on the Colleges, The Manufaktur-Kollegiya (manufactures) and the Berg-Kollegiya (mines and metallurgy). Thus when the Bavarian, E.J. Lindemann applied to establish a large-scale woollen cloth and silk manufacture in Russia the College refused on the grounds of high cost and labour demands. Once licences were gained the foreign entrepreneur enjoyed specific privileges and exemptions. [65] In Russia, by a variety of methods the state determined the employment of transferred technology in enclavist, increasingly concentrated industrial enterprises.

In XVIIIth century, Spain, a combination of local state governments, nobility and the Church promoted a programme of technology 'improvement' cen-

[63] Bartlett, *ibid.*, p. 179.

[64] *Ibid.*, pp. 216-229.

[65] *Ibid.*, pp. 143-47.

tred on the Sociedades Econömicàs de Amigos del Pais — Friends of the Country. We have seen that the first of these was founded in the Basque region in 1765, (section II above). In 1774 the fiscal of the Council of Castile, the Conde de Campomanes published his *On the Development of Popular Industry,* of which some 30,000 copies were distributed to local officials and clergy throughout the nation. The resulting flourish of interest centred on the improvement ethos of European science, acclimatisation and scientific agriculture, and was associated with programmes of educational reform, technology transfer, translation and research. Royal favour endowed professorships in economics, chemistry and mineralogy. By the years of the French Revolution 56 such regional improvement societies had been formed. Although vehicles of the European enlightenment, the prime function of the Spanish societies was the establishment of specific skills and vocations. Schools were instigated for instruction in weaving, mathematics, mechanics, design and economics. Where in the North *savants* gained prizes and recognition, in the peninsula young girls were rewarded with money and jobs.

In the economically-backward states of Western Europe, war alone could have similar impact on the transfer process — Sommering in Munich brought the electric telegraph to the relief of Napoleon in 1809. In place of salaries and direct finance, governments used subsidies, monopolies and tariff concessions to induce strategic transfers. In Belgium, King William I not only became a major shareholder in Cockerill's Seraing Works (wool carding and spinning) but also sold him the Seraing estate as a site at a 'trifling price'. The success of Prussia in Silesia prior to 1786 stimulated a programme of technological transfer under the paternalist management of Frederich the Great. The first stage was policy which encouraged internal development; the erection of state shipyards, the establishment of agencies for the marketing of Silesian iron ore, tariff protection and the granting of selective monopolies in salt and timber, and privileges in cutlery and munitions manufacture, sugar refineries and metallurgical works. At the second stage, Prussian officials in Silesia organised techninque transfers into the region from France, Belgium, Switzerland and Britain. The visit of the government agent G. von Reden to Britain culminated in the introduction of steam engines, coke furnaces and iron-puddling. It was Reden who first employed William Wilkinson as manager of an enterprise, as well as the Scot, John Baildon to manage the newly introduced coke furnaces.

In France the royal privileges became a significant instrument of transfer policy. Transferred technologies which produced goods in direct competition with British imports (hardware, plated wares, copper work) were sure of gaining privilege. The factories into which de Wendel, Wilkinson and Morgan brought their technologies were established by Royal privilege. Ministers such as Turgot, Necker and Calonne distributed awards, subsidies and privileges to a variety of innovative *French* entrepreneurs on the technical advice of Englishmen such as Holker or Milne.

In Britain, the stimulus given by the state to technology transfer or improvement was even more indirect. Technological change was undoubtedly encouraged by the internal 'environmental' effect of the Navigations Laws, the imperial ambitions of statesmen and a host of private legislation designed to maintain and encourage the development of harbours, rivers, turnpike roads, canals and agricultural improvement. Of over 3000 private and public Acts of the 1740s and 1760s, 20% were for turnpike road schemes alone. [66] As we have suggested, most *direct* government aid in England was directed to navigation and agriculture. In improvement-oriented Scotland the Scottish Board for Fisheries and Manufacturies was involved in the use of new technologies in road and canal building. British bureaucrats were much more active in the encouragement of colonial technology transfer. In 1749 parliament passed an Act exempting from duty all raw silk which was certified to be the product of Georgia or Carolina. A bounty was also offered for the production of spun silk and an Italian, G. Ortolengi was hired to proceed to Georgia to instruct the colonists in the Italian methods of sericulture and silk throwing. In 1761 the London Society of Arts offered additional premiums for the production of good quality American cocoons. Under Italian methods such stimuli led to a filiture complex for reeling, doubling, cleaning and twisting. [67]

E. *Trade and Transfer.* Foreign trade could introduce new products to consumers and thereby indirectly stimulate the internal *demand* for the foreign technologies which produced them. Machine or chemical technology could be imported directly for military or other needs. The demand of other nations for exports of iron or silk or timber might encourage the transfer of technologies into these areas of the national economy. *Financial* gains from trade could provide the foreign exchange resources needed to purchase machinery, personnel and skills. Therefore, it comes as no great surprise to learn that the acceleration of the transfer of technologies from the mid-XVIIIth century, was associated with a rise of European trade. The value of world trade rose by as much as one-third in the years 1740-1780, and 75% of this was carried in European vessels. Capital was attracted to trading sectors just as the extension of markets encouraged technical innovation and importation. But this loose *association* was, in fact, a

[66] For an exhaustive historical treatment see Chapters 4 and 8 of W.T. Jackman, *The Development of Transportation in Modern England*, London, 1916, revised 1962

[67] For this and the subsequent history of transferred technology into American silk manufacture, see L.P. Brockett, *The Silk Industry in America*, New York, 1876. During 1733-35 Thomas Lombe acted as technical advisor to the Trustees of Georgia in their attempts to grow and throw silk using Piedmont methods.

two-way relationship rather than a simple causal one; technical developments in Europe produced the vehicles of an expanded trade, the armed merchant vessel, the iron cannon, the 'floating epitome of European civilisation'. [68] In addition, technical change reduced impediments in areas ancillary to sea-going transport systems. New technologies were embraced in the deepening of the Ghent-Bruges canal, the improvement of the Schleswig-Holstein canal, the reformation of the Louvain-Aachen road system. Most of this ancillary-trade development occurred after 1780. [69]

The transferal effects of trade could be considerable. In 1782 some 60% of Hungarian imports were of sophisticated manufactured or semi-manufactured goods. Furthermore, the balance of trade was very often in favour of colonies or less-developed areas (e.g. the French West Indies). Treaties which opened up foreign competition were at times *designed* to promote greater technical efficiency. Landes has suggested that the 1786 commercial (Eden) treaty between France and Britain, which exposed the French market to British cottons 'made modernisation a matter of survival'. [70] Normal market competition could have the same effect. In the later XVIIIth century, Russia's penetration of the British market for iron, together with the emergence of coke-smelting and puddling in Britain itself, induced Swedish efforts to revamp her technological capabilities by direct transfers. The Swedish Board of Mining and Metallurgical Industries (Bergs-Kollegium) and the privately organised Iron Bureau (Jernkontor) joined forces in their efforts to meet the dual threat to their major foreign market. Sven Rinman of the Jernkontor sent an assistant to Britain in 1767 to make a particular study of the new cast-steel process. From 1796 the increase of import duties on Swedish iron led to a concentrated programme of technology importing, investigative tours and translations in Sweden. A trade in goods often carried within it a trade in journals, transactions and scientific instruments. [71]

But a *financial* gain from trade did not *necessarily* entail a process of modernisation through either technological rejuvenation or transfer. Here, the *pattern* of

[68] A. Milward & S.B. Saul, *The Economic Development of Continental Europe 1780-1870*, London 1973, quote p. 105.

[69] *Ibid.*, pp. 112-13. A factor in choosing the site of the Le Creusot works (text above) was the construction of the Saone-Loire canal systems.

[70] D.S. Landes, *The Unbound Prometheus*, Cambridge, 1969, quote p. 139.

[71] Esp, p. 44 of T.H. Levere, 'Relations and Rivalry: Interactions Between Britain and the Netherlands in 18thc Science and Technology' *History of Sience, 9*, (1970). For Sweden see K.G. Hildebrand, 'Foreign Markets for Swedish Iron in the 18 thc', *Scandinavian Economic History Review, VI*, (1958); E. Söderlund, 'The impact of the British Industrial revolution on the Swedish Iron Industry' in L.S. Pressnell (ed.), *Studies in the Industrial Revolution*, London, 1960, and Flinn's introduction to *Svedenstierna's Tour of Great Britain 1802-03*, Newton Abbot, 1973.

Russian commerce, which extended to control of the highly profitable shipping enterprises, continued throughout the century. By the 1750s at least 50% of all Russian trade was with the British and was characterised by a large *surplus* balance for Russia. However, Britain was importing Russian naval stores and raw materials for industry but was exporting little of any industrial or technological significance to Russia. So the link certainly stimulated British commercial shipping and industry but exerted little impact on industrial development within Russia, and possibly served to direct indigenous muscovite merchant capital away from industry. [72] The Commercial treaty of 1734 did swell the coffers of the Russian government, a windfall gain similar to that which fell to the Spanish economy during the great, colonial years of bullion inflow into Europe. But writing from St. Petersburg in 1767, the English ambassador, the Earl of Macartney observed that there was not a Russian counting-house in any foreign country, that very few Russians chose to freight a ship on their own account. French penetration of the Russian market in the next decade offered little in the way of an alternative trade model. In 1772, the satirist N.I. Novikov, in his *The Painter* wrote of the recent arrivals from France,

> 'Trifles from Marseilles, in twenty-three days. They have brought us the following necessary goods: French swords of various kinds, snuff boxes made of tortoise shell, papier-maché, and lacquer; laces, blond lace, fringes, cuff, ribbons, stockings, buckles, hats, cuff links and all sorts of so-called haberdashery wares; Dutch quills, in bundles, sharpened and not sharpened; pins of various kinds, and other fashionable petty goods. The ships will load various Russian trifles in Petersburg, namely hemp, iron, Russian leather, tallow, candles, linen and so forth. Many of our young nobles laugh at the stupidity of the French who sail so far to exchange their fashionable wares for our inconsequential trifles'. [73]

Once more it seems clear that the effective transfer and diffusion of technologies required more than knowledge, energy or money.

IV: Human Capital: The Transfer of Skills

At many points we have seen how the transfer of a technology or technology package depended on more than initial change agents. Human capital was required to settle techniques, to get them going and to maintain, adapt and repair them. Even nations indisputably advanced in technique and the culture which produced it were at times dependent on imported skills in particular industries

[72] D.K. Reading, *The Anglo-Russian Commercial Treaty of 1734*, New Haven, 1938.

[73] N.I. Novikov, 'The Painter' in N. Blinhoff, (ed), *Life and Thought in Old Russia*, Philadelphia, 1961.

or projects. As Mathias has reminded us so clearly, the later eighteenth century technologies required the employment of new and increasingly specific skills. The intermeshed group of skills in engineering — precise metalworking, (boring, planing, turning and cutting), the use of sophisticated machine tools, the construction of joints for cylinders and pistons — were not yet available at large. [74] This is true of Britain. The construction of the swivel loom in Britain in the mid-eighteenth century depended on the invitation of Dutch mechanics to Manchester. [75] The great ironmaster Abraham Crowley utilised the skills of workmen from Liège in his works in the North East. Mathew Boulton recruited metal workers from France and wrote to Vienna, Belgium and Sweden in search of engravers. Workmen of the St. Gobain Works in Picardy were employed in the Ravenshead plate-glass works at St. Helens in 1783. The general skills of the American artizanal homesteader were also augmented by necessary imports from abroad. In his tour of 1794, the British woollen manufacturer Henry Wansey described factory complexes based on government grants, foreign machinery and foreign skills. A woollen and cotton manufactury at Connecticut was granted the sum of $10,000, promised a further $60,000 and depended upon selected British workers rewarded with high wages and incentives. A water powered cotton factory in New Jersey was run by 14 skilled men drawn from Manchester who supervised the construction and maintenance of Arkwright machinery drawn directly from British models. In New England the iron establishments of the Salisbury district were developed by Swiss and Russian workers. When the former Strutt employee, the mechanic Samuel Slater, was employed by the textile firm of Almy and Brown at Pautucket his own skills were sufficent to guide those of American artisans. By 1790 the firm was constructing carding, drawing and roving machines, and at a slightly later date the newly trained American mechanics were able to establish firms of their own, backed by American merchant capital. Slater's firm had an enormous impact in America — by 1820 the bulk of the cotton goods produced in New England came from these or associated firms, equal to perhaps one-quarter of the value of all manufactures produced in America. [76] Mechanics could gain in other ways. Amos Whitteman, the farmer's son who invented an improved carding machine in Massachusetts, patented it in 1797 and then sold the patented machine for the princely sum of $150,000.

Mechanics were quite as prominent as transfer agents and technological entrepreneurs in Europe. The 'peripatetic mechanic' Jean Wassiege of Liège was

[74] Mathias, *op. cit.*, (ftn. 47), pp. 33-35.

[75] Levere, *op. cit.*, (ftn. 71), p. 47.

[76] D.J. Struik, *Yankee Science in the Making*, New York, 1948, 1962, pp. 192-6. Henry Wansey, *An Excursion to the United States of North America in the Summer of 1794*, 2nd edn., Salisbury, USA, 1978.

in 1751 constructing Germany's first steam engine, used for a lead mine. In the same year the English catholic and Jacobite engineer, John Holker (1719-1786, see above) was establishing his cotton mill at Rouen. Under the command of the comptroller-general of finance, Holker enlisted 25 skilled Manchester men in 1754. One such was Michael Alcock, a metalworker, who from the 1750s acted as a French recruiting agent for the metal industries. For placing British mechanics in the armaments factory at Saint Etienne, Alcock received a fee of 2,400 livres. Between that time and 1780 Alcock emerged as a foremost French entrepreneur. Similarly, in the 1790s English artizans operated mule-jennies at Bernhard's cotton mill in Saxony. Around the turn of the century Lieven Bauwens brought 17 mule-jennies and 40 skilled operatives for England to Ghent. In XVIIIth century Spain, French, Flemish and Swedish engineers and mechanics flooded into both private and state-instigated industries. Although the earlier pilot factory for woollens at Guadalajara met technological difficulties, the establishment of a strong Flemish settlement aided in the later success of modernised woollen factories in Béjar.

Starved of European skills, Russia once more offers a prime example of dependent, monitored borrowings. Artizans attracted to Russia could become registered members of guilds, which under state regulations included formal apprenticeship training. In the silk producing area of Astrakhan (Volga region, see above) foreign artizans soon became entrepreneurs in their own right. Johann Svenson arrived there as part of the entourage of a European silk manufacturer in 1763. He obtained a government grant of 5,000 roubles and established a large enterprise using German looms. From Hamburg in the next year came A. Verdiev and Jean Roux, who received a grant of 6,000 roubles for the erection of sericulture and silk weaving establishments, as well as grants of land and the obligation to train Russian apprentices. They were later successful in selling their thriving business to Russian merchants. During the same decade Swiss clock and watch producers and German hatters received similar inducements under identical obligations. [77] By 1766 the Petersburg craft-guild community contained 777 German and 562 Russian master craftsmen.

V. Conclusions and Generalisations

A. *Reservations.* Any attempt to draw firm conclusions from such a great variety of material faces three major problems. The first relates to the *stochastic* features inherent in knowledge-technology creation and transfer. Although the *internal* diffusion of either knowledge or machines may be explained by reference to cultural, social or economic factors, at least during the eighteenth century

[77] Bartlett, *op. cit.*, (ftn. 59), pp. 143-179.

creativity and transfer were in large part associated with the basically unpredictable activities of individuals and institutions. In this area there is a high degree of randomness attached to specific events. This problem applies more to science than to technology. Secondly, it is not possible to simply *accumulate* instances of scientific or technological transfer as evidence of relative success: five instances of technology transfer did not necessarily have greater significance than two other instances. Thirdly, and closely related, the economic *impact* of transferred technique remains in most cases problematic. Even highly *successful* technological projects — such as those at the Rouen factory in the 1760s, or the Baird works in Russia from the 1790s or Slater's textile technology in America — may have absorbed as much in the way of scarce economic resources as would alternative indigenous techniques. Detailed case-histories are required in order to satisfy this point. To an economist at least, a shiny new machine or a foreign accent is not always 'better' than a hand-tool or the local dialect.

B. *Knowledge as Capital.* Several examples have been given of the very large private gains which could be obtained by 'owners' of knowledge or technology eg. the salaries and pensions of the intellectuals in France, the high incomes gained for institutional or public lecturing in some nations, John Harrison's £20,000 for the chronometer in 1772, the commercial rewards of a successful patentee or secreted invention or from a novel organisation of production, (Lombe's factory), the large grants at times offered by the state for new transferred technologies (Ador, Barral, Alcock), the monopoly profits derived from 'privileges', or the $150,000 gained by Whitteman by selling his patent in 1797. Put against the fines for intellectual spying or the costs of an Arkwright mill, these were very considerable sums. [78] One of the most interesting features of eighteenth-century Europe is the apparent contradiction between the ready movement of information about technologies and the high private gains to be made in their application.

C. *Initial Transfers.* On the whole the first transfer of new technology involved a simple set of procedures. We have argued that *overall* relative spatial (cost and time) proximity, the spread of general scientific and specific technical information and the needs of the state, combined to promote frequent and

[78] Given that buildings and some machinery could be converted from one line of production to another with relative ease, the establishment costs of a small-scale cotton mill (jennies, mules, capstans, building) was around £1000-£2000 in the 1780s. For a purpose built factory of the Arkwright water frame type, £3000 might be needed. Thus, Harrison's reward could have made him a 'manufacturer' 10 times over; the government revenue granted to the Connecticut woollen works in the 1790s might have purchased 2 or 3 Arkwright mills in England.

speedy transfers in the eighteenth century. There were exceptions. John Wilkinson refused to help J.C. and A.C. Perier when they attempted to build a Boulton-Watt steam engine in France in 1777. In the next year Watt failed to secure his own patent protection in France. When patent protection was gained J.C. Perier secured rights to manufacture in France using Soho specifications, at a fee of 48,000 livres. But another 'change agent', Cockerill, was legally inhibited from actually importing a Boulton-Watt engine into France until 1813. Two generalisations may stand the test of further historical research. In *nations* or *industries* where the receptor state was particularly concerned (e.g. generally in Russia or specifically in armaments) the transfer process was likely to be swift and to cut across barriers represented by either legal restrictions, war or market forces (e.g. an insufficient demand for the product in the receptor economy at large). Second, prior to the first industrial revolution there had not yet been sufficient *demonstration* of the economic and political repercussions of new technical applications in the *industrial* sector to warrant massive activity by merchants or entrepreneurs in transferal of technology. Transfers, therefore, were often epiphenomenal to the cultures and economies of receiver nations, and were introduced under the pressure of military-prestige factors rather than market forces. If transferred technologies were cost-efficient then this was a bonus.

D. *Transfer and Appropriate Technology.* The total transfer process can be given a model schema. An initial import of machinery and personnel gives way to a capacity for repair and maintenance, within which process indigenous skills are revamped; this may be followed by renewed transfers in other regions, related industries or infrastructure (e.g. canals), in which process a portion of newly-skilled indigenous artizans and entrepreneurs will be active; this may culminate in the ability to *construct* and *maintain* the initially transferred archetypes; the learning-process may also induce an ability to improve or modify the originally transferred techniques in a *range* of industries. We might generalise from this that failure anywhere in the schedule might result from the *inappropriateness* of the original technique on several levels. We know that the scheme was not easily completed in most instances. Mule-spinning was *transferred* to Normandy in the 1780s, but machines were not *constructed* there until 1803. Boulton and Watt steam engines were quickly transferred to a variety of nations, but long lags in the ability to construct efficient copies at a commercial level are evident, extending to perhaps 35 years in an economically 'advanced' nation such as France, to 45 years in Russia. But it is difficult to specify the *reason* for such lags in a period when many transfers were instigated by government/official actions which were not necessarily responsive to market forces. In the case of the steam engine it might be true that the transferred 'package' was not complete. But it might equally be argued that under the historical conditions the *construc-*

tion of machines was less *appropriate* to the receivers than their continued importation i.e. the latter may have cost less. Similarly, early attempts at diffusing modern methods of woollen production failed at Guadalajara, Spain. The scale of production was far too great for the intended market, and the Madrid warehouses were soon overstocked, the goods produced were both inferior to those of the woollen cloth of Barcelona and more expensive than the high-grade production of Abbeville. In most cases, the private entrepreneurs were reacting to prevailing market forces, and not to the long-term needs of the state, about which few of even the bureaucrats or statemen could be very sure.

E. *Appropriateness and diffusion (internal)*, what of the process involved in the internal diffusion of transferred techniques? Technologies which required large amounts of fixed capital (private or revenue) and high initial running-costs (e.g. mines, canals, engineering works) and which involved a long period between initiation and the production of a final, marketable product, or which required the skills of unavailable or costly labour, were often quick to transfer but slow to diffuse within receptor nations. Technology may not diffuse because it is too costly, supplies an insignificant market or a product which does not fit the 'tastes' of consumers or producers, competes with readily available internal produce (e.g. handicraft industry) or cheap imports, [79] or utilises raw materials which are not available internally, obtainable only at great cost, or available in forms (e.g. iron, coal) which do not lend themselves to *effective* utilization (eg. in furnaces designed for different quality ores). The *technologically* successful textile complex at Yamburg, Russia, inspired by both foreign entrepreneurs and the state, failed because of a combination of such reasons. Under market inducements a repair facility could act as an intermediate agency in the transfer process. The repair shops which developed in Switzerland to service imported British spinning machinery were eventually transferred into machine factories.

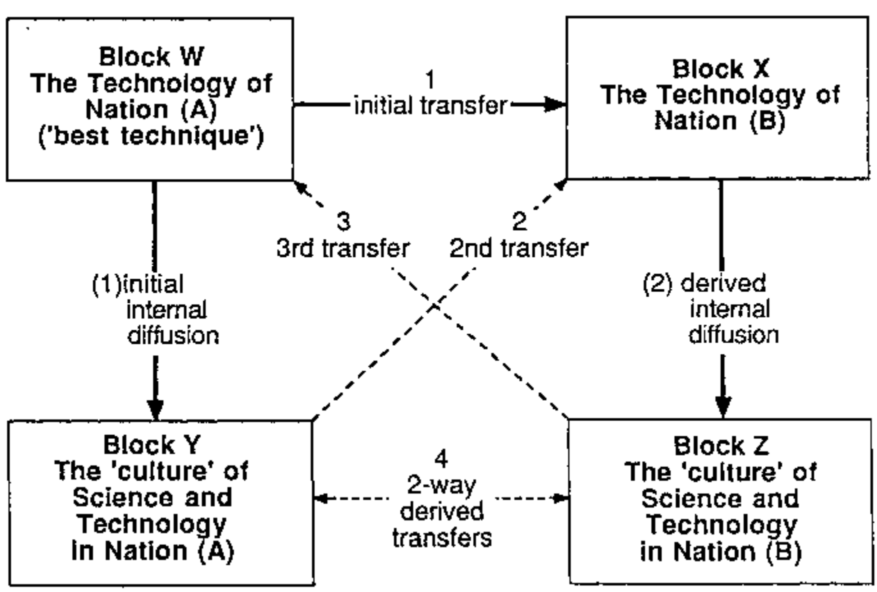
If transferred technology is highly inappropriate and therefore not successfully 'indigenised' there are two possible results relating to the diffusion process: (1) If the social and economic environment of the receiver is, coincidentally, similar to that of the source diffusion, depends only upon knowledge and entrepreneurial zeal, and much of both existed through at eighteenth century Europe, Russia and America: (2) Where the internal skills, spatial or financial environment is greatly different from that of the originator of the technology, and where markets for goods are different in size or nature ("tastes"), transfer will be either unsuccessful or will be concentrated into *enclaves*. If enclave pro-

[79] Although *transferred* quickly, the Leblanc method of soda production did not become widespread in Britain for some 30 years, and this was probably because British producers possessed ready and inexpensive sources of barilla and kelp.

duction is reasonably cost-efficient (which it may still be) then it will achieve a monopoly status within the economy (e.g. French technique in Northern Italy, Barral's production of tin in Russia, Slater's production of textiles in America, or the more insidious monopolies gained through state privilege or patenting). Whether this represents the *diffusion* of an efficient technology, that is, the better allocation of economic resources, will depend on the subsequent price effect.

Monopolies or near-monopolies may dictate prices, especially in nations where market forces are yet developing. In situation (2) it is perfectly possible that the transferred technology will represent a tax on the total economic system. Even here, however, the *historical* or longer-term impact might be positive in terms of non-financial gains. Learning processes or the introduction of servicing technologies might induce efficiency at another time or in another sector. We might conclude that many eighteenth-century transfers had a minimal or even negative impact on national production at the time, but that such transfers began to exert more positive effects at a later date.

F. *Transfer, Diffusion and Flows.* During the eighteenth century, under which conditions was a transfer of technologies from A to B most likely to result in diffusion within B or C, or subsequent transfers from B to A? Chart 1 below exposes a possible series of relationships, and conforms to much of the qualitative evidence above.



In our simple scheme, Nation A creates a specific technology at Block W. Through a variety of available or constructed mechanisms this transfers directly out into Nation B (Block X) as well as into the technological infrastructure and economy of Nation A (Block Y). Phase 1 is complete. However, from the technological culture of Nation A (Block Y) the original but perhaps modified (by theoreticians or 'tinkerers') technology is now available at various points of production or usage or experiment. From all of these further transfers (second transfer arrow) to Nation B (or an equally hypothetical Nation C) may take place. The technology has not been effectively captured by one 'owner'. If Nation B (e.g. Russia) possesses little in the way of a *comparable* science-technology culture, *or* if market forces are insufficient to induce replication or modification, then technology in Block X remains *enclavist* and unadapted. Technologically (although not financially) Nation A has not benefitted. However, if the technology transferred into Block X diffuses into the existing culture of technology in Nation B (Block Z) this will increase the *likelihood* of further technological flows, (third and fourth transfers). Modifications of the originally transferred technology in Block Z may flow back to its origin or be incorporated as yet another element in the technological culture of Nation A (Block Y). The existence of general scientific and technological information dispersed throughout a nation's culture helps not only in the diffusion of 'best practice' within *that* nation (it cannot in itself *cause* this), but increases the likelihood of an eventual two-way flow of technical information or of technology embodied in capital between leading nations. For purposes of *historical* analysis we might hypothesise that such a dynamic process was beginning in the years prior to 1780 and accelerated thereafter. If we were to argue that it was primarily in *England* that new technologies were produced within a strong culture of science-technology, then the historical tendency would be for the major flows to be one-way, out of England. This is precisely what did happen towards the end of the century. The industrial revolution may have occurred in Britain first *not* because that nation boasted best technique or *received* more technology through *transfer* than any other nation, but because, from whatever source it came, new technology in Britain was 'applied' in the market place i.e. diffused at large. Other nations became net receivers of technology but were less able to diffuse it because of their lack of an *equivalent* culture of science-technology. Britain also gained *financially* from her exports of technology when they were embodied in *capital* equipment. We might postulate that the variations in the free *supply of knowledge (the relative strengths of science-technology cultures)* could have been *permissive* factors in the process of initial industrial revolution. Spatial and market forces, on the other hand, may have served to *promote* industrialisation, in terms of their effect on both the demand for best-technique and on the *diffusion* of existing technologies *within* nations.

G. *Industrial Revolution.* This paper has not attempted in any way to argue that the transfer of scientific knowledge, or of machines and skills, was necessarily of great importance to the industrialisation of receiver nations in the eighteenth century. Holker may have been relatively successful, but most transfers failed at some level. What we have argued is that the *relative ease* of transfer of techniques or the discrete knowledge upon which they were based or improved, illustrates that the mere *possession* of a technology or set of technologies is not a sufficient explanation of the industrialisation process. Technologies transferred. The nation which *industrialised* was the one which diffused, modified and improved existing techniques, brought them out of their origin in enclaves and into the market place. The explanation of the internal diffusion process must lie in a complex of cultural, social and economic factors, the character and momentum of which lie beyond the scope of the present essay.