Potentially Global. A Story of Useful and Reliable Knowledge and Material Progress in Europe circa 1474-1912.[1]

Ian Inkster

For those European economic historians who are determined to use their special insights and expertise in order to address some of the great questions concerning the global history of the material world, there are several approaches that might be adopted in an effort to avoid the diminishing returns that undoubtedly do set in when the conversation remains only global.[2] The first tactic is to analyse 'The West', and to do so in a manner that somehow captures the whole and its margins without presuming that the lessons learnt about material advancement are somehow universal.[3] The second tactic is to focus on the 'Best of the West', to take those exemplary regions of Europe and America that seem to have been the very epitomes of the essence that we are attempting to capture. Thus a renewed interest in pre-industrial Smithian growth and in the British case, not merely as a cumulative industrialisation, but possibly once more as a profound Industrial Revolution that through its very exceptionality may yet shed light on the material fortunes of both Europe

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[1] This article is an adaptation of two presentations to the global history group . I would like to thank Gerry Martin and Patrick O'Brien for involving me so closely in the global history discussions of the Achievement Project and in the Global History Seminars of the Institute of Historical Research since 1989, and for the insights and corrections provided in lively discussions with Simon Schaffer, Rob Illiffe, Alan Macfarlane, Harold Perkin, Bin Wong, Kent, Floris Cohen, and others of the GEHN group I would also like to acknowledge the value of the battles over Eurocentrism that I have fought with my Taiwanese students since the moid-1990s, but especially the cultural sensibilities and scepticisms of my graduate student Jerry Liu during years in both Taiwan and England

[2] As an example of redundancies and repetitions in the global history debate see 'Frank-Landes Debate. ReOrient versus The Wealth and Poverty of Nations', " December 1998; http://www.whc.neu.edu

[3] For a fine example see Sidney Pollard, *Marginal Europe. The Contribution of Marginal Lands since the Middle Ages,* Clarendon Press, Oxford, 1997.,

and the globe. A third tactic is to analyse the connectivities and contrasts between 'The West and the Rest' in order both to stress inter-dependencies of material advancement across entire civilisations – and certainly throughout the Eurasian landmass of and through the Oikoumenê as well as to develop a methodology of comparison that might somehow allow the historian to isolate those historical processes or episodes that really were of paramount importance in explaining the great divergence.[4] A fourth tactic requires a career change and much work in language laboratories, and is that which involves considering 'The Rest' of the globe as material and cultural phenomena in their own right, and then attempting to uncover the trajectories and regimes that operated between and within such other places whilst bringing to this task some considered insights and expertise derived from scholarly knowledge of the Western experience. To even attempt the latter in a manner that is at once scholarly and non-eurocentric is an all but impossible task.[5] In the present paper we adopt tactic two above, whilst looking over our shoulders at the other possibilities.

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[4] It is surely not too generous to suggest that this was, in the end, the main concern and tactic of Toynbee's major work. More success might lie at more modest comparative levels – see Alan Macfarlane, *The Savage Wars of Peace, England, Japan and the Malthusian Trap,* Palgrave Macmillan, Houndmills, 2003. For the newer and broad-brush approaches see Jack Goldstone, 'Cultural Orthodoxy, Risk and Innovation: The Divergence of East and West in the Early Modern World', *Sociological Theory*, 5, 1987, pp. 119-35; S.A.M. Adshead, *Material Culture in Europe and China, 1400-1800. The Rise of Consumerism*, Macmillan Press, Houndmills, 1997; an interesting comparative approach is adopted in W.P. Alford, *To Steal a Book is an Elegant Offense. Intellectual Property Law in Chinese Civilization,* Stanford University Press, Stanford, 1995, especially chapter 1, and given the emphasis on patenting in the present paper it is of note that this author finds little functional equivalence between the early Chinese system and that developing in Europe, although it should be noted that he perhaps takes insufficient account of the reward and honour elements in Euro-patenting prior to the 1830s, the efficiencies, corruptions and monopolies that clouded their functions as intellectual property systems at that time. He does not draw on the work of Macleod or of Hilaire-Perez and tends to fall into comparing historical China with all-but contemporary Europe or America.

[5] But not impossible, as the text-book work of Susan Naquin and Evelyn S. Rawski, *Chinese Society in the Eighteenth Century*, Yale University Press, New Haven, 198t, and the interpretive work of Kenneth Pomeranz, The Great Divergence, Princeton University Press, 2000 illustrate.

1. The Character of the Questions.

There is an argument expounded by several historians that a regime of Useful and Reliable Knowledge (henceforth URK) was of necessary importance to the emergence of the material dominance of the West in global history. Prior to the 18th Century some combination of the 3Rs (the Renaissance, the Reformation, the Scientific Revolution) might well have been salient to the emergence of a new west that was increasingly situated to challenge the world after an earlier period of catch-up.[6] In this approach the 18th Century remains of strategic importance as the site of a watershed that in a way was both commanding and transcending – the world from that point could not go back. In this perspective it may be possible to argue that the key productions, disseminations and applications of useful and reliable knowledge took place during the long 18th Century rather than much before it.

The greater recognition by economic historians of the seeming importance of specific knowledge associations and sites of activity at particular times is of course welcome, and does not of itself require an apanage of any Landes-style arguments concerning their ancient origins.[7] Thus in a recent incisive review, Nick Crafts at one point admits that a 'striking feature of 19th century Great Britain was the mushrooming of associations that were designed to spread technological knowledge'.[8]

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[6] For warnings about implied contrasts and concerning the breadth of our ides of useful knowledge, see A.W. Crosby, *The Measure of Reality*, Cambridge University Press, Cambridge, 1998.

[7] David Landes, *The Wealth and Poverty of Nations,* London, 1998. Here Landes posits that Europe's material superiority lay far away in the Judaeo-Christian past, when a unique combination of private property rights and belief in sovereign power circumscribed by God's authority and jurisdiction 'made Europe very different from civilisations around' and allowed pockets of dissent and initiative, see pp. 35, 336-342. For some of the origins of his comparative stance see E. Balazs, *La Bureaucratie celeste: reserches sur l'economie et al societe de la Chine traditionelle,* Paris, 1968.

[8] Nicholas F.R. Crafts, 'The First Industrial Revolution: A Guided Tour for Growth Economists', *American Economic Review*, 86, 1996, pp. 197-201, quote p. 199. Crafts goes on to conclude that it is 'clear that British capabilities for the transfer and

The real question is, in what manner is this 'striking' and how was it of importance? Merely because other nations seem to have possessed less of this characteristic, or because this characteristic is now seen as particularly pertinent, or both of these? Together with the notion of a system open to other influences, this point binds together the great tradition of historical writing from David Hume circa the 1740s to William Ashton circa the 1940s, with the formers 'emulation and novelty which contribute so much to advancement' and the latter's 'coming and going between the laboratory and the workshop'.[9] Of course, the engineers had long claimed a special place for a quantitative and qualitative improvement in technologies as the primary cause of British industrial forwardness. Thus the classic statement by William Fairbairn[10], civil engineer, LLD, FRS, President of the Manchester Philosophical Society, who if anything emphasised a singular slowness of change until 'a new era dawned upon our industrial resources, when invention and enterprise revolutionized the commercial interests of the nation, and placed it at the head of all civilized states through the introduction of machinery, by which the greatest and the most delicate operations imaginable are effected. With what wonderful precision and exactitude are the various and intricate

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improvement of technology were strong and improving during the first industrial revolution, and this no doubt was central to the (otherwise surprising) steady acceleration in Total Factor Productivity growth. This is not, however, captured by conventional measures of schooling, nor does it necessarily translate into a rapid increase in skills of the average production worker… If a key role for human capital in growth is to facilitate the absorption and effective implementation of technological advance, a more sensitive approach both to measurement and to modelling is highly desirable.' (p. 200). For an approach to Japanese industrialisation that directly links government expenditure on human capital formation to technology transfer and absorption see Ian Inkster, 'Capitale umano e trasferimento di tecnologia. Il caso giapponese in una prospettiva di lugo periodo', *Annali di Storia dell'impresa,* XI, (Spring, 2000), 379-400.

[9] David Hume, *Essays , Moral, Political and Literary, London 1741-2*, quotes as in Vol. XXXIII of the *Works of David Hume*, London, 1903; T.S. Ashton, *The Industrial Revolution 1750-1850,* London, 1948, p. 16.

[10] 1789-1874, especially notable for successful construction of two water-mills at Zurich in 1824, engineer for the Turkish government, and superintendence of construction of the tubular bridge across the Menai Straits in conjunction with Stephenson in 1848.

operations of the cotton manufacture performed! With what rapidity and despatch is a pound of the raw material converted into yarn, and the yarn into cloth, passing through a series of self-acting machines, all of which only require feeding, or a transfer of the material from one machine to another, to produce the perfect article!' Furthermore, Fairbairn was quite prepared to analyse the British technological ascendancy in machinery and motive power in terms of Newtonianism, the new chemistry, the laws of definite proportions, and how these were in turn modified and advanced by subsequent machine investigations into a type of virtuous circle of URK-improvement. For example, new ideas 'of much greater precision, and more in accordance with philosophic data, began to prevail in regard to the properties of matter, and established a material theory fitted to render a more intelligible explanation of calorific phenomena.'[11] Fairbairn saw the spectacular machine improvements of the 1830s onwards as specifically arising from formal developments in URK (especially relating to heat and friction) associated with the research programmes of Rumford (Benjamin Thompson, 1753-1814) and J.P. Joule (1818-1889). Finally, Fairbairn completed his argument with an attempt to demonstrate the importance of specific urban associations in the circulation and application of URK within industrialising Lancashire and Cheshire. In this he went far beyond the much quoted Manchester Literary and Philosophical Society[12], with which he was long associated, to detailed instances of knowledge-technique relations in The Manchester

[11] William Fairbairn, *The Rise and Progress of Manufactures and Commerce in Lancashire and Cheshire,* Manchester, 1869. Separately published this volume also composed vol. II of J. Baines', *Lancashire and Cheshire, Past and Present*, quotes pp. iii-vii.

[12] He did note the scientific-technical links in the work of such outstanding MLPS members as John Dalton, William Henry, Eaton Hodgkinson and Joule, pp. xvii-xxviii. He also emphasised the URK character of the society's *Memoirs* and *Transactions* from 1781. For a study which minimised the direct industrial and technological outcomes of the MLPS see the highly influential paper by Arnold Thackray, 'Natural Knowledge in Cultural Context: The Manchester Model', *The American Historical Review*, 79 (1974), p. 672-709.

Natural History Society, The Manchester and the Liverpool Royal Institutions, the several mechanics' institutions of the region, the Liverpool Philosophical Society and Queen's College and the School of Science and so on.

Questions might now surely relate to the How of it all, the specific role of it all, and the cost of it all? For instance - In what manner exactly was Britain at this time so peculiarly endowed? Why does this matter when there are so many other possible explanations of British advancement? Were there costs attached to this world of association that might have offset any gains?[13] Are historians able to go beyond lose generalisation and towards the description of sites of advantage and of how they evolved and worked?

Again, the national systems economists have recently discovered that the most fundamental resource for the nation is knowledge and, accordingly, that the most important process is learning.[14] But how much have they thought of what learning and of where the learning takes place, and how and why and by whom? In the absence of just such elementary questions we end with stories of peculiarly western scientific knowledge

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[13] There is much ambivalence here, especially as to so-called costs of an early institutional start. Once institutions are established their structures and functions may fall into a path-dependency from which they may not easily escape, even in the face of new industrial competitors who appear on the industrial scene amidst innovative URK and other institutions. Fairbairn (op. cit. especially pp. xxxii-xxxv) was in confusion over this point when after lauding the benefits to Britain of urban associations to circa the 1850s he moved into a contradictory position in a lecture to the Manchester Working Man's Institute, where he first argued that Britain was not failing in 'skill and perseverance on the part of our mechanics and artisans' but rather was facing 'the advance that other nations of late years have made in the productive arts', but then went on to argue that 'during the last forty years, the better class of mechanics and artisans abroad are better educated than the corresponding class in this country'. A clamour of such special pleadings (in this case, for compulsory primary education) led to the long debate on the character of British industrial decline and suggested the extreme shortness of Britain's institutional lead!

[14] For technical versions of this approach see C, Freeman, 'The national system of innovation in historical perspective', *Cambridge Journal of Economics,* 19, 1995, pp. 5-24; D. Rooney and T. Mandeville, 'The knowing nation; a framework for public policy in a post-industrial knowledge economy', *Prometheus*, 16, 1998, pp. 453-67.

and peculiarly western technological outcomes, with faith rather than history filling the obvious gap. I think we might now wish to consider this gap. Else we are in danger of agreeing with the emerging new consensus in world and industrial history without providing the modifying and specifying role of professional historical guidance and analysis. So at this stage I would like to suggest some pointers and some generalisations, and a few findings too.

Both the conventional and the new stories about knowledge and artefact tend to forget the How question in favour of Why, Where and When questions. Secondly, they elide the distinction between the conditions of creating and diffusing new ideas and techniques, and the conditions for transferring and adopting them. Thus, on the naïve face of it, whatever the cultural or commercial 'failures' of a system or civilization in not coming up with gravity, the vacuum or the electric circuit, the lens, the steam engine or the micro-chip, these may be entirely unrelated to any failure to adopt, adapt and advance such breakthroughs speedily but subsequent to their creation in some other Elsewhere system or civilization. Furthermore, the two sets of lacunae are connected quite intimately – the themes concerning creation/creativity/insight/first achievement do tend to lead to Why questions, even to God Herself, whilst the problems of the transference and adoption of ideas and techniques do tend to be better answered at the more mundane level of the How query.

Any assaying of such an agenda confronts a Frankian perspective that in essence denies the strategic importance of both knowledge and the 18th century. At one point – and perhaps several others – Gunder Frank argues that material dominance by the west, whilst laid out in the Columbian Exchange, only measurably took effect from circa 1800, and that such dominance only became obvious and irreversible around

1850.[15] In the 1950s the great Arnold Toynbee gave a wonderful lecture in Canberra in which he argued that the end of Western dominance was to certainly be found in the Chinese and Turkish rebellions, insurrections and revolutions at the beginning of the 20th century, if not in post-modernities emerging circa 1870. An extreme vision might then suggest a squeezing of Western dominion into the period of a Frankian 1850 to a Toynbeean 1870, and this seems to approach farce, neatly inversing the equally farcical take on euro-history in Monty Python and the Holy Grail.

2. The Long Swing: How Much Euro-URK before circa 1700?

The first premise of this section is that 'culture' is complex and possibly of less importance in material change than proximate environment - all vicinities or sites of technological and other change contain fragments (or representations) of a larger culture, but they are not themselves the entire cultures, systems, civilisations or whatever the working term. The long sweep, then, is not very usefully only a story of contending philosophies and cognitions, but must include a less-determined account of site and agency. A second premise is that URK is involved in moments of insight, the raising of awareness of a problem, in the setting of a stage for its articulation, in critical revision or in communication from the original sites. Diffusion, adaptation and application - all are feasible processes in which reliable knowledge had a role, but there is no reason to believe that they were ever arrayed in a linear manner at all. Such processes had a real life in physical sites, for to follow Margaret Jacob, significant material applications of reliable knowledge indeed 'are the work of human beings encoded with values,

[15] Andre Gunder Frank, *ReOrient: Global Economy in the Asian Age,* UCP, Berkeley, 1998.

entwined within social networks, decorated with symbols of status, people whose ideas are glorified or forbidden by religious beliefs and practices'.[16]

On such an understanding it is possible to highlight some major features of European history into the 18th Century.

It seems clear that the early years are made up of specific skilled sites – from German potters (stoneware, salt glaze) and paper mills and rolling mills and printing (described by Gutenberg in 1460 as 'proportion and harmony of punches and types'), through Dutch canal building, Portuguese navigation and ship construction (Madeira and the lateen sail), to English military arms (the longbow of Henry V, the cast-iron cannons of Ralph Hog in 1542). In this early period we might also identify a tendency towards (not much more than that) increasingly Europe-wide techniques – clock-making, cast iron production, geometrification of cathedral building, bit and brace drilling, and by the 1530s the spinning wheel, although only in advanced places the foot treadle or twisting rotation for the latter.

These years were associated with both the rediscovery of technical classics or the new investigation of earlier advances – Ptolemy's Geography translated into Latin in 1406, the discovery of the Vitruvius manuscripts De architectura around 1410, Conrad Mendel's publication 1423-29 of the so-called Mendel book which depicted 355 medieval crafts. Property rights[17] began on knowledge applications - from 1421 in

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[16] Margaret Jacob, *Scientific Culture and the Making of the Industrial West,* OUP, New York, 1997, p.1.

[17] We do not wish to detail here the issue of defining property rights, and thus their possible ancient origins. Between 1331 and 1452 letters of protection were issued in England to foreign weavers and other craftsmen and in 1347 there was a complaint in Parliament against an alien merchant monopolising the export of Cornish tin. See G. Aldous et al., *Terrell on the Law of Patents,* 11th edition, London, Sweet and Maxwell, 1965, p.6. The first known patent as such was issued by the Republic of Florence in 1421.

the Republic of Florence to the English Statute of Monopolies in 1623[18]. The decree of 19 march 1474 concerning the 'protections of inventions in the republic of Venice' was notably addressed to 'men from different places and most clever minds, capable of devising and inventing all manner of ingenious contrivances'. Henceforth any such new contrivance was to be noticed before the Provisioners of Common, by which the projector gained10 years protection, with any infringement costing 100 ducats and the destruction of all the equipment of the guilty party. Most famously, in 1594 was awarded the granting of a patent to Galileo by the Doge on behalf of the Republic of Venice for a device for 'raising water and irrigating land with small expense and great convenience', on condition that it was truly novel. Of significance was Galileo's dual plea for protection, for it became the standard argument for intellectual property rights in the West. In his petition he claimed 'it not being fit that this invention, which is my own, discovered by me with great labour and expense, be made the common property of everyone', and that with protection 'I shall the more attentively apply myself to new inventions for universal benefit'. His privilege covered 21 years.[19] In 1499 the Italian Polydore Vergil in his De inventoribus rerum was discussing the inventors and inventions of printing, glass, ships, and gunpowder amongst much else. The new striving for reliability was focussed on time, place and cartography, and the first global map including America was published in 1,000 copies in 1507. Gemma Frisius' De principis astronomiae et cosmographie in 1533 showed that longitude was obtainable from comparison of mechanical clock-time with Sun-time, and

[18] Actually enacted as The Statute of Monopolies, 25 May 1624, 21 Ja. C.3. For it and cases under it, including the foolish monopoly awarded to the Elizabethan courtier Darcy see H.G. Fox, *Monopolies and Patents,* University of Toronto Press, 1947.
[19] The Venetians granted some 1600 such privileges in the 15th and 16th centuries mostly as copyrights, with only a small proportion of recognisable mechanical inventions. See 'History of the Patent Office', Centennial Number, *Journal of the Patent Office*, 18, July 1936.

the first European book on shipbuilding, De re navali appeared in 1536 and the Mercator map projection in 1568. We might claim that this range of knowledge was increasingly reliable.

In contrary mode, states and authorities frequently attempted the suppression of reliable knowledge or its isolation from artisans and producers - from the prohibition of all new doctrines by the Emperor Charles V at the Diet of Worms in 1519 or the Index libvrorum of 1559, to the threats of execution by the Grand Duke of Florence for any brocade worker leaving town. More mild in terms of physical butchery, but clearly directed towards the reproduction or application of URK, were the restrictive impositions of bodies such as the Star Chamber[20] or the increased regulations restricting printing of seditious material, as represented by the English Printing Act of 1662. If only to counter a common assumption, it should be emphasised that the state attempted to direct the flow of all knowledge, including URK, whenever and wherever possible and that this was probably most effectively accomplished in the most 'advanced' regions, where the authorities could utilise the common institutions of civil life as regulatory intermediaries. The exclusion of books from the 1484 Act passed to restrict the conditions whereby aliens could work or trade in England suggests a relative liberalism, followed by a toughening of attitudes through the acts of 1523, 1529 and 1534, that together brought all foreigners in all trades under the rules of the Companies, to be subject to search by their Wardens and confiscation of goods and assets. From then restriction were placed on both the

[20] The Star Chamber was, as one commentator has put it, 'marvellously well adapted to deal with unlicensed booksellers and heretical writers'. In 1637 the Chamber codified the law on printing by a decree of 33 clauses that gave power to the Company of Stationers as official registry but reserved to the Archbishop of Canterbury and the Chancellors of the two English universities the right to license books of divinity, medicine, and philosophy (or , broadly, science). See Augustine Birrell, *Seven Lectures on the Law and History of Copyright in Books*, Cassell and Co., London, 1899. The Star Chamber was abolished in 1640, but during 1642-3 the House of Commons continued its work in searching for and destroying seditious pamphlets and imprisoned the vendors and printers.

knowledge of strangers and all publications that might be seen to be in any way heretical or seditious. Thus the 1557 Charter of Philip and Mary incorporating the Stationers' Company, some eighty years after Caxton began to print at Westminster, 'wishing to provide a suitable remedy against the seditious and heretical books rhymes and treatises which are daily printed and published by divers scandalous malicious schismatical and heretical persons'.[21] This was confirmed under Elizabeth (through legislation in November 1559) and it has been summarised that the subsequent Elizabethan book trade was indeed 'a controlled output' and that by the acts 'the Government rendered the task of surveillance and control of the nation's reading comparatively easy'.[22] Subsequent development within the Court of the Company itself sought to increase their monopoly power over knowledge, even in the face of various contemporary attacks on privilege more generally, and they continued a vigorous process of search and prosecution against printers, booksellers and bookbinders throughout the years 1586-97. Prosecution could result in imprisonment without trial.

To such statist restriction might be added the resistance of workers themselves (often stirred up or focused by yet other interests); thus the riots in Gdandsk, Poland in 1596 in which the inventor of the ribbon loom was strangled. However, the great bulk of artisan and townsman revolt, from the small masters, compagnons and apprentices of the lowest of 17th Century crafts, to the coopers, dyers, masons, weavers and wrights, seem to have concerned local disasters or the impositions of increased taxes, tolls or corvees, or the impacts of novel financial institutions, rather than the introduction of new machinery or work processes. It is surely of note that the supposed 'popular' attacks tended to be directed against

[21] C. Blagden, *The Stationers' Company: A History 1403-1959*, London, 1960; W.W. Greg and E. Boswell eds., *Records of the Court of the Stationary Company 1576-1602: Register B*, London, The Bibliographical Society, 1930.
[22] Greg and Boswell op. cit. p. lxi.

houses and farm buildings, trees and vines, stacks and outhouses.[23] The main point of popular contention in Europe was feudal rent and corruption, not new machines.

More than compensating for the suppression attempts of European states was the impact of state ambitions and warfare within Europe upon the dispersal of knowledge and skills. This may be difficult to quantify but should not be underestimated in any qualitative approach - thus the fall of Constantinople in 1453 and the influx of Greek scholars into Italy, the invasion of Italy by Charles VIII of France in 1494 and the consequent migration of Italian workmen to France, the 1527 sack of Rome and the dispersal of Italian skills throughout Europe, and the famous case of St. Bartholomew's in 1572 and the move of the Huguenots to England, France, Holland and elsewhere.[24]

Key European sites were terrains of information gathering and communication, and such terrains were physical and institutional. Publication articulated and transferred reliable knowledge between sites. In 1569 was published Jacques Besson's Theatre of instruments and machines, which describes a lathe and what in Europe was possibly the first workable screw-cutting machine. For four centuries from 1588 was reprinted and copied A. Ramelli's Livres des divereses et artificieuses machines, an illustrated machine book. By the end of the 15th Century some 35,000 different books had been published and printed in Europe, possibly around 20 million copies, of which perhaps 40% dealt with moral and religious matters. In the early 1600s the first European newspaper was published in Antwerp. One of the first journals specifically for artisans

[23] Of course there is much debate. see T. Aston ed., *Crisis in Europe 1560-1660*, Routledge and Kegan Paul, London, 1965; P.J. Coveney, ed., *France in Crisis 1620-1675*, Rowman and Littlefield, Totowa, NJ, 1977.
[24] Charles R. Ashbee, *A Table of the Arts and Crafts of the Renaissance,* London, 1892.

was published in England from 1691, the Collection for improvement in husbandry and trade.

To pass a threshold of reliability, continuity and influence, such sites needed to contain something in the way of expert markets - some audience that harboured but tested the new and was characterised by an accepted minimal degree of trust and civility, itself a basis for both celebration and authentication.[25] During the 1560s were founded the first institute devoted to research on nature and mechanics, in Naples, and the first industrial exposition was held at Nuremberg in 1568. Such sites for the creation and manipulation of reliable knowledge increased through time in number and variety. Raleigh's first colony in the New World in the 1580s included a smelting laboratory designed to test ores for gold and silver

Competitive statism and shared borders forged 'the strength of weak ties'. This needs a little explanation and extension. Drawing on some reasonable social theory as well as some intuition we may follow Harry Collins in his notion that there might be a useful combination of 'thin' connections and 'dense' communities by and through which reliable knowledge emerges. So, European-city dense areas might have served to act as breathing spaces (e.g., freedom from guilds or social restrictions or loss of local face), offered places for the building of knowledge assets, confidence and identity, and an audience, permitted recovery from failures, acted as centres for the circulation of printed information, encouraged 'neighbourly'[26] emulations and incrementations, recipes and

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[25] For which in its very best form see chapter 2 of Steven Shapin, *The Scientific Revolution,* University of Chicago Press, Chicago, 1996 and his detailed study *A Social History of Truth: Civility and Science in Seventeenth-Century England*, UCP, Chicago, 1994. Now we are in a world of euro-assets that are not easy to emulate or transfer and are not eptly uncovered elsewhere.

[26] T. Hagerstrand, *The Propagation of Innovation Waves*, Lund, 1952; idem., 'Quantitative Techniques for Analysis of the Spread of Innovation and Technology', in C.A. Anderson and M.Y. Bowman eds., *Education and Economic Development*, Chicago 1965, pp. 244-80. To historians it may be important to point out that in this sort

verbal knowledge of experiments, and helped in the definition of domains of knowledge. But too much density can forge a conservatism, a series of new conventions that might help in diffusion and in raising reliability but could curtail novelties - in intense communities scholars and practitioners chase each others' tails and Aristotle emerges the victor. Thus the importance of loose or weak ties, especially between such communities, and via correspondence, travel, and print media, which bring together distant and foreign elements, features perhaps essential to Mokyr-like 'punctuations' - technical breakthroughs feasibly linked to reliable knowledge.[27] Loose ties involve civility and trustful communication over distance i.e. between people who are neither seeing each other nor threatening each other. We suggest that it is difficult to find this combination in places other than Europe,

Loose ties yield a greater probability of migrations and the active presence of 'strangers'. This has been developed a little by economic historians interested in the conditions for the development or limitation of markets - on the edge of markets as strangers appear the cost of transactions rise sufficiently to bind the market until something is done.[28]

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of approach supplies of information might be more stimulating than new types or levels of demand, and that a) innovation adoptions and diffusions are the outcome of learning processes, and because diffusion is across both physical and social space then factors relating to the effective socio-geographical flow of information become paramount, and b) expansion of specific information – especially in our formulation, URK - may reduce resistance to technological change. It is also worth noting that urban areas may have provided more freedoms, but that the guilds were not in themselves inhibitors of technical change in a world of putting-out, indeed they may have been principle suppliers of neighbourliness of the Hagerstrand kind in that apprentices had to learn not only technical skills but about 'negotiation with other artisans, labourers, and merchants' (Epstein p. 688); see especially S.R. Epstein, 'Craft Guilds, Apprenticeship, and Technological Change in Pre-industrial Europe', *Journal of Economic History*, 58, 1998, pp. 684-713.

[27] Joel Mokyr, *The Lever of Riches*, OUP, New York, 1990, where the formulation in the latter section is, of course, quite different than this. For a series of essays on the evolutionary analogy for technological innovation see John Ziman ed., *Technological Innovation as an Evolutionary Process,* Cambridge University Press, Cambridge, 2000.

[28] See for instance the interesting paper by K.A. Chaudhry, 'The Myths of the Market and the Common History of Late Developers', *Politics and Society*, 21, pp. 245-74.

But this theme is probably of greater importance as an approach to useful and reliable knowledge. Too much density encourages the rejection of the stranger and provides the strength and confidence to do so. In contrast, loose ties involve points of penetration or infusion of new people, new knowledge, new artefacts. Examinations of migrations within Europe suggest the central importance to the early-modern period of avenues of reception (naturalisation, guild membership, matriculation,) reward (election to office, patents) and internalisation (admittance to charitable activities such as poor-relief systems, freedom of the city, honorary positions, intermarriage, inter-worship, commercial partnership with indigenous population). These together attract strangers, allow them to attain a civil and a civic status, promote the giving of knowledge and its estimation as reliable. Through the avenues depicted, from the Jewish diasporas of the south - note the impacts of their expulsion from Spain in 1492 - to the Huguenots of the north, the social networks were forged, values encoded and symbols of status awarded in a Jacob-like manner. Can we find sites of this sort outside Europe and in sufficient profusion and freedom? May the State (e.g., in Russia or China) substitute for such elements of public and private space?

A brief case-study of the work of the engine-wright in Europe from Denis Papin in France and England to Georg Winterschmidt at the Hartz Mines in Germany circa 1680-1750s might give some general notion of the complex saliency of the relations of URK and technique into the 18th Century.[29] It seems clear that formal knowledge training was of some real

[29] I refrain from copious footnotes but must cite two very good recent studies from which I am drawing at this point - Alan Smith, 'A New Way of Raising Water by Fire: Denis Papin's Treatise of 1707 and its Reception by Contemporaries', *History of Technology*, 20, (1998), 139-82; Christoph Bartels 'Georg Winterschmidt's Water Pressure Engines in the Upper Harz Mining District 1747-1763: Plans, Experiments, Problems, Results', *ICON, Journal of the International Committee for the History of Technology,* 3 (1997), 24-43. For insights into the long-term see Bartels, 'The Development of the Turm -Rosenhof Mine, 1540-1820, Clausthal, Upper Harz': *MASCA Research Papers in Science and Archaelogy* 6: History of Technology; The

importance, as with Papin at the Huguenot academy at Saumur and his Angers University MD. Perhaps formal learned association was more evident – e.g., the association with the Royal Academy of Sciences, Paris, and especially the assistance of Christiaan Huygens, the positive influences of Gottfried Liebniz. Of importance was movement between sites of experimental knowledge – so from Huygens, Papin passed to Oldenberg, the Secretary of the Royal Society of London, assistant to Robert Boyle. With work on the air-pump continuing, Papin then associated with Robert Hooke, and with Savery became FRS in 1680. Papin obtained direction of the Venetian Academy of Sciences during 1682-4, then the Chair of Mathematics at Marburg in Hess-Cassel. Key individuals acted as great communicators e.g. Leibniz at Hanover, or negative judges e.g. Newton in London, and experts as verifiers of reliable knowledge, as in the post-1707 debate at the Royal Society regarding steam engines. Similarly, there is great evidence of the vital function of instrumentation and instrumental expertise - Papin's calibration of Huygen's air-pump, the test of the comparative worth of Savery and Papin (1707) engines. Experimentation served several purposes, especially perhaps in the establishment of reliability amongst expert audiences - the experiments of Papin in the 1680s at the Royal Society on the vacuum, atmospheric pressure, and pneumatic transmission of power followed by his twenty-year experimental program in pneumatics and mechanics at Marburg and Cassel.

Publications possessed something of a similar multi-functionality, as announcements, credentials, and, importantly, binders of small knowledge-communities eg., Papin's 1674 Nouvelles Experiences du Vuide was later serialised in the Philosophical Transactions in England,

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Role of Metals (Philadelphia 1989), 47-64. The generalisations of my text also try to take into account the more general European steam power and engine work of these years, including Thomas Newcomen's atmospheric beam engines from 1712, Thomas Savery's work on high-pressure steam, the piston-less pump or *The Miners Friend.*

in turn Boyle and Hooke both included annexes of his work in their publications etc. We might note the Royal Society publication of A New Digester in 1681, and the first reliable report of Papin's method of producing a 'perfect' vacuum by allowing steam to cool under a piston published in Leipzig's Acta Eruditorum within weeks of its discovery in August 1690. Publications also aided in transformation of reliable knowledge into technique - eg., the Recueil de diverses pieces of 1695, the Philosophical Transactions of 1697, the Nouvelle maniere pour lever to 1707. The steam engine chronology also illustrates the importance of European officialdom for both stimulation and reward – in amongst their well known intellectual roles, Huygens was the Dutch director of Louis XIV's Royal Academy, Gottfried Leibniz was a German diplomat, Sarotti the Venetian ambassador in London, Papin acted as paid adviser to the ruling Landgrave of Cassel. Finally, we might add the seeming importance of property rights in attracting attention and capital as with Savery's patent, which secured investment and protected the later Newcomen invention from early competition.

In brave summary - In the years from around 1150 to around 1500 it does seem that Western Europe demonstrated significant technological innovation. But this can not easily be put at the door of euro-nationalism or culture or policy per se, as much change then centred on the Islamic areas of Spain, emanating outwards from North Africa and the Middle East - thus the new metalworking, mining and architecture, and the general diffusion of printing and paper making and the associated use of the water-wheel in pulping. But by the end of this period, Europe itself was advancing, and this was possibly an outcome of increased statist rivalry and emulation. Such statism was set against the background of the decline of Islamic influence and the relative absence in Europe of natural disasters and set-backs, which together encouraged a measurable increase in trade and communications, in urbanism and new life-styles, and an accelerated transfer of technical knowledge from advanced to backward areas in such industries as glass and paper making. The observable struggle towards reliability and accurate reportage was closely linked to navigational and military needs, focused around the imperatives of euro-expansion. A well-known example was that of the Portuguese prince, Henry the Navigator (1394-1460), who set up an observatory and school of navigation on the south coast at Sagres, where there gathered pilots, cartographers, philosophers and shipbuilders, all aiming at the exploitation of the mysterious west coast of Africa and generating improvements in the astrolabe, the compass and other techniques and instruments. The Iberian explorations required improved compasses, geometric quadrants, and astrolabes, advances in ship technology, including piston pumps for draining (notably improved in 1545 by the Spaniard Vicente Barroso) and diving equipment. The effective exploitation of the Americas involved advances there in water milling generally and grain grinding and sugar crushing in particular. Finally, for every state that rejected skilled minorities, more than one other instituted policies for their reception and reward, from grants of land and property-rights to membership of guilds and fraternities. From the South to the North, such movements were through social networks which to lesser or greater degrees encoded values and awarded status to those with skills and new knowledge. We might conclude that, prior to the eighteenth century, government influenced the generation of reliable knowledge and its applications mostly through military demands, migration and skilling legislation, providing havens for minorities, and instituting something of a system of intellectual property rights.

The European scientific revolution, if such may be identified validly,[30] depended for its emergence on places of experiment and trust

[30] For which, of course, see Shapin, *Scientific Revolution* op cit., especially pp. 1-14. One of the principal meanings of Shapin's initial statement that 'there was no such

and avenues of knowledge articulation, expansion and diffusion. Its principal elements, of measurement, experiment, classification and physical modelling, depended on but required moving far beyond older patterns and norms of craftsmanship. Techniques were spurred by increases in demand, but also by the invention of the associated institutions of the market, of plantations and factories, and by a background radiation of divisions of labour based on better use of existing techniques. In great 'other places' such as China or India, this configuration appears not to have worked so intensively - trust and civil living, increased domestic and military demand, places of experiment, acceleration of the media of communication and knowledge articulation, together with altered imperatives stemming from the need to exploit new areas of the globe in a system of national commercial, naval and military competitiveness, did not appear in 'conjuncture' elsewhere in the world at this time.[31] Although much of this lay beyond any European state or policy regime, we might conclude that the principal function of the state at this time was to provide base and infrastructural support (or environmental facility) to the emergent scientific endeavour, rather then to interfere in the workings of science itself, the certifying of experiments or the codifying of what was good in the new.

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thing as the Scientific Revolution' is that he can not defend 'anything like an "essence" of seventeenth-century science', this giving rise to a multiplicity of stories, some of which then go on to assert its peculiarly western origins and characteristics.

[31] For arguments as to the URK aspects of the great discoveries and their commercial exploitation see Carlo Cipolla, *Guns, Sails and Empires: Technological Innovation and the Early Phases of European Expansion 1400-1700,* New York, 1965; Michael Adas, *Machines as a Measure of Man: Science, Technology and Ideologies of Western Dominance,* New York, 1989; William Storey ed., *Scientific Aspects of European Expansion,* and Michael Adas ed., *Technology and European Overseas Enterprise* as vols. 6 and 7 in the series An Expanding World, Aldershot, Variorum, 1996; Roy MacLeod and Philip Rehbock eds., *Nature in its Greatest Extent: Western Science in the Pacific,* Honolulu, 1988; and a review of the issue in Ian Inkster, 'Global Ambitions: Science and Technology in International Historical Perspective 1450-1800', *Annals of Science,* 54, 1997, pp. 611-622.

Lewis Mumford famously concluded that the 'culture of cities is ultimately the culture of life in its higher social manifestations'. Much earlier indeed, Aristotle had claimed that people congregated in cities 'in order to live: they remain together in order to live the good life'. Under what local or other conditions does this 'good life' naturally incorporate reliable knowledge? Did such conditions exist scattered around the globe prior to 1600 or 1815? In places in Europe which exhibited densities and weak ties together, reliable knowledge seems to have been intrinsically associated with civil cultures which transformed power into polity and experience into science. But reliable knowledge was tested and applied in other places, in the houses of gentlemen, in isolated associations, in academic or scholarly isolation and in village workshops. The dynamic relations between such places perhaps require some new analysis. But if such variety existed it is yet feasible that reliable knowledge in non-European places may have been created, articulated and expanded in locales which were more like villages and workshops or Z Places than cities, towns or royal societies. This surely requires elaboration by comparative or global historians?

There is no evidence of an increase in the price of URK in Europe as we move into the 17th century and 18th century, which means either that it was of little relevance to material pursuits or could only be applied at prohibitive cost and high risk on the one hand, or that it was oversupplied for reasons that had little to do with the costs of its production or the directly commercial needs of its purveyors or conveyors.[32] The second argument, positing a cultural or institutional

[32] More work needs to be done on the price of knowledge in books, transactions, collections and translations, lotteries and exhibitions, demonstrations and lectures, membership of associations and so on. Evidence on basic tools of skilled workers, such as lathes, may be indicative also – Rogers suggested falling prices between 1401 and the 1560s with some rise thereafter. From that point they seem to have stabilised in England. See, James E. Thorold Rogers, *A History of Agriculture and Prices, vol. IV, 1401-1582*, Oxford, Clarendon Press, 1881, pp. 463-73.

oversupply of URK seems the strongest possibility from the evidence - for instance even after circa 1815 in England the price of reliable knowledge was measurably falling, not rising.[33] Thus we are concluding that because in Europe the pursuit and purveyance of reliable knowledge was markedly disengaged from any direct commercial considerations but was rather the cultural reflex of large groups with many interests, and because knowledge expands with use, then the price of reliable knowledge could fall through time (including the years of the crucial 18th century) despite its increased importance as an input (process, energy and raw materials innovation) into a widening variety (product innovation) of material productions. Another conclusion might be that the resources that produced reliable knowledge were not valued at all fully (in Smithian terms) in markets, by interests or by states. We would further argue that this was peculiarly the case in Britain.

3. URK and the 18th Century Turning Point

Until the 18th century, any case for uniquely powerful ideas and institutions in Europe that ensured future material victories seems to rest on shifting and unsafe grounds. But I continue to believe that we may still make reference to the 18th Century in terms such as And Then Something Happened. There are lots of reasons for this, beginning with demography and the extent of non-agricultural output produced by combinations of skill, coal and metal, but with reference to reliable knowledge and my points above about site and agency, then I would emphasise with Jacob and others that it was particularly in this century that investigative styles, modes of replication and verification were brought forth from 'science' into 'technique' within the limitless interactions of an eighteenth century

[33] See the varied empirical evidence in Ian Inkster, *Scientific Culture and Urbanisation in Industrialising Britain,* Variorum, London, 1997.

associational culture which did not, indeed, differentiate knowledge from applications. Jacob rightly refers to the new 'vibrancy of civil society in the form of voluntary associations for self-education and improvement', and for her the rationalism of the European entrepreneur was not merely a Smithian given but rather a decision-inducing cultural trait derived from enlightenment science, from experiment, controlled indications of likely results, improved habits and instruments of observation. Accepting this as reasonable, then we may wish to note the accelerations of earlier euro-trends during the 18th century.[34] But we might also claim that the eighteenth century was the period when the very notion of mechanism was seen as unconfined, applicable to morality and a new humanity as well as to all things material. Thus Simon Schaffer has indicated how in his exemplary sites enlightened 'philosophers tried to build for themselves a position from which they could describe the mechanisms that governed nature and humanity' as the world in which entrepreneurs and projectors worked and plied their trades.[35] Recently, Mokyr has combined these notions in his term 'Industrial Enlightenment', which he envisages as a 'set of social changes' that both 'sought to reduce access costs by surveying and cataloguing artisanal practices in the dusty confines of workshops, to determine which techniques were superior and to propagate them' and also 'sought to understand why techniques worked by generalizing them, trying to connect them to the formal propositional knowledge of the time, and thus providing the techniques with wider epistemic bases'.[36] This makes sense in terms of our URK schema,

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[34] For sources and details Ian Inkster, 'Technological and Industrial Change: A Comparative Essay' in Roy Porter ed., *Eighteenth Century Science,* Vol. 4 of *The Cambridge History of Science,* CUP Cambridge, 2003, pp. 845-881.
[35] Simon Schaffer, 'Enlightened Automata', in William Clark, Jan Golinski and Schaffer, eds., *The Sciences in Enlightened Europe,* University of Chicago Press, Chicago, 1999, pp. 126-65, quote p. 129. Here Schaffer shows us wonderfully well the Enlightenment project of identifying labourer and machine, one vision of which was the automata.
[36] Mokyr, *Athena* op. cit., pp. 34-41. For propositional knowledge see further below.

although we would add that the effectiveness of such savant intentions lay in things other than the world of knowledge only, in a wider institutional conjuncture that appears to have been at its most appropriate for industrialisation in England and Scotland. I differ from Mokyr in thinking that the agencies involved were located often well away from those more savant groupings who were delving, beavering, cataloguing and reporting, and thus that his 'interaction' of propositional and prescriptive knowledge took place at sites beyond the ken or the view of his Baconian philosophies. Again, this was true more in Britain than in, say, France. Finally, understanding of the industrial implications of such interactions requires understanding of the changing urban and associational environs in which they took place, especially from the 1780s onwards.

In advanced sites in Europe, much that had gone on before, now accelerated, a feature of the century that should not be neglected or maligned – acceleration can mean the passing of a threshold, from which new kinds of impact may be discernable. Official blockage on the movement of reliable knowledge now becomes completely ineffectual - thus the introduction via the foreign settlement there of 65,000 French citizen mechanics into Spain of French techniques and institutions at the beginning of the century despite legal restrictions and active policing. Nothing much better was accomplished by migration prohibitions in Austria or harsh penalties on technology disclosure in Sardinia. Competing states accelerated their efforts at the enticement of skills and machinery and reliable knowledge, a better known-story. More forgotten are the effects of war and acquisitions on skill accretions – for instance Prussia in Silesia to 1786 and the technology transfers of Frederick the Great. Probably of more importance were migrations created by statist conflicts, as in the Spanish example above. In more advanced commercial sites, earlier restrictions faded from use, as with the loosening of the power of the Companies and the 1696 lapsing of the earlier printing act. This allowed the emergence of professional book wholesalers who speeded up the geographical diffusion of all printed matter, this aided by copyright acts (in England from 1710) that permitted unrestricted import of works in European languages with 14-year protection given to all new copies of earlier works.[37]

However wasteful of resources in the shorter term, the 18th Century saw statist measures to reduce the distance between forward and backward sites, to industrialise their traditional military pursuits, to raise the tail of the Lumbering Average. This took many forms but was probably more effective when centred on increasing reliable knowledge by mass skill migration. Thus Russia after 1762 with the establishment of the 'frontier' settlements of Germans, Moldavians, Belgians and Armenians. 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. There was a measurable speeding up of 'chance meetings' across much of Europe, perhaps more than elsewhere, and by these British citizens brought iron foundries, blast furnaces and textile machinery to France and Sweden, advanced sites supplied textile machinery to Bohemia, Moravia and Lower Austria, and at the other end of the century Italy's techniques came from France, Estonia's from German commercial groups, Spanish woollen innovations from English, Dutch, Irish and French artisans.[38]

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[37] John Feather, *A History of British Publishing,* Routeldge, London, 1988, pp. 69-74.

[38] For detailed studies of overt and prolonged commercial attempts at technology transfer, mostly concerning Britain and France, which illustrate brilliantly the importance of the character of institutions of site and agency see John Harris, *Essays in Industry and Technology in the Eighteenth Century*, Variorum, London, 1992, especially the classic transfer studies in chapters 3 and 4. For his and others' related studies see C. Crossley and I. Small eds, *The French Revolution and British Culture*, Oxford University Press, Oxford, 1989 and D.J. Jeremy ed., *International Technology Transfer in Historic Perspective*, Edward Elgar, London, 1991.

Population movement was into denser places (see above) than ever before. By 1800 the number of cities with populations of over 10,000 reached 363, reflecting an increase in the urban ratio in the north and west extending from the early 17thc. The particular growth in the early 18thc of administrative-military capitals induced utilisation of reliable knowledge in arsenals and ports, sites of bronze, copper and iron metallurgy employing outworkers in small artisan shops. Later-18th Century urban growth boosted the size of the smaller units, by which cities of over 5,000 population increased in number by around 50% and these tended to be sites of modernised metallurgy and water-powered textiles. Movements between denser places were stimulated technologically to a greater degree than before - investments in roads, canals and coastal trafficking in the Dutch Republic, in Britain and the Atlantic ports of France and Germany promoted an increase in speed and reliability and safety at lesser costs, and mostly represented a spread of methods rather than new innovations.

The denser, more open places were the sites of and for associations, cultural societies, booksellers, newspapers, printing companies, and novel forms of intellectual and technological discourse e.g. coffee houses and public lecture courses, from which were built expert audiences, information systems, competitive spaces for emulation, social spaces for the construction and reconstruction of individual status and civic identity. The first of the great alphabetical encyclopaedias, Bibliotica universale sacro-profana was published by V.M. Coronelli of Venice in 1701, the first clearly technical college in Europe, the Schemnitz Mining Academy was founded in Hungary in 1733.

Reliable knowledge media increasingly locked knowledge with technique. The first publication of R.J. Eliot's invention for smelting iron from black magnetic sand, demonstrated in Connecticut, was published in the Transactions of the Royal Society in1762, John Keir's Dudley alkali works were directly inspired by P.J. Macquer's Dictionary of Chemistry, John Roebuck's attendance at scientific courses at Edinburgh and Leiden transposed to chemical engineering, and these are but tips of a huge communication system controlled by nobody but its users. Major innovators were themselves embedded in publishing and communicating, e.g. after discovering the role of carbon in the hardening of steel Rene de Reaumur published L'art de convertir le fer forge en acier in 1722, which is the first 'reliable' European technical treatise on iron. Most conveyors of reliable knowledge automatically compounded technique with abstraction - thus Francis Hawksbee's Physico-mechanical experiments of 1709 and his lecture courses from 1712 at the time when he was incrementally improving Newton's simple electric generator of 1709, or Thomas Savery's Treatise on fortifications of 1705 or, most brilliantly, Jacob Leupold's Theatrum machinarum generale in 9 volumes during 1723-39. There was a great swelling of books overtly delivering reliability to expertise, possibly serving to articulate the tacit (see above), as with Charles Plumier L'art de tourner of 1701 on the lathe for turning iron or Jethro Tull's Horseshoeing husbandry of 1731, or more generally B.F. de Belidor's La science des ingenieurs of 1729, frequently reprinted into 1830. Thus the many chance meetings of artefacts and skills. Thus Braudel's 'technological and political accidents combined with favourable economic circumstances'[39], a phrase that I trust I have here refined a little.

Very broadly, technology itself was more clearly now serving the monitoring and reliability of knowledge, providing feedback to the momentum of the knowledge-production relation - thus in 1716 Mary Butterworth and note-counterfeiting, the mass of new work on

[39] Ferdinand Braudel, *Civilization and Capitalism 15th-18th Century,* Vol. 2, *Wheels of Commerce*, Fontana Press Edition, London,1985, p. 570.

escapements and time-keeping, ship's log improvements, the 1731 invention of the sextant ... and so on.

4. The Big 18th Century Issues

In recent years, several historians have argued that in advanced Europe during and after the 17th century, science of some modern, sceptical and experimental kind, flourished amongst key groups in cities, academies and associations. As we have indicated, such groups were increasingly fed by an industry of publication [the prices of whose products were falling throughout the 18th century] and stimulated by new commercial incentives that induced for a host of diverse reasons a high status position for useful and reliable knowledge amongst large congeries. What remain unclear are the answers to the How questions. Knowledge was available in lots of sites – reliable knowledge expands with use – but was only specified, valued and applied in some. How did such processes occur? Many agents moved knowledge around, only certain places made much of that, forged knowledge into material process or mechanical artefact. Precisely how was this done? Any answer to questions of how URK or any form of new articulated knowledge was applied to material progress in particular sites, requires at the outset that we abandon portmanteau conceptions of science, that we establish the invisibility of the knowledge-technique dichotomy within the knowledge culture of 18th century Europe, and that we understand that social and geographical proximity really, really matters.

Those concerned with the science-technology relationship, linear or otherwise, have been overly worried about the lack of temporal proximity between the Scientific Revolution and the Industrial Revolution – the one lay too much afore of the other. This worry pales into insignificance compared to the real queries concerning social and spatial proximities.

The place on earth that could increase the social and geographical proximities of URK and technique was surely at something of an advantage? Did increased proximity over larger numbers of folk and places (some version of Mokyr's Industrial Enlightenment) take time to forge, perhaps close to a century? In the 18th century was this indisputably accomplished in the West? Within the West, was Britain indisputably at an advantage in terms of such social and spatial proximities by, say, the mid-18th century? To prove that there were cheaper and better and many more useful books per capita in Europe than in China or in India is of little aid to analysis in itself. This might be irrelevant or reflect still other and perhaps more profoundly explanative factors, such as higher disposable money incomes or larger numbers of independent scholarly and professional associations and institutions.[40] More directly, such a large comparison tells us little of the recognition, ownership and application of truly useful and reliable knowledge. Greater understanding of the latter – which was in the end the query set so long ago by the Clows, Musson and Robinson, Armytage, Pollard and Mathias, who were all more vigilant about URK than ever they were about 'science' – might not only yield comparative global insights, but might also begin to address the old vexing question of Why Britain of all European Places?[41]

It now seems astonishing that the early work of historians such as Musson and Robinson was so frequently brought to task by more general economic historians for failing to demonstrate the 'truly scientific'

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[40] Printed subscription lists to particular works of 'scientific' URK are of course available and have been seriously analysed, but they may not as such be extrapolated to gross measures of all European (or any other) literature of the 18th century. See the innovative work of the Newcastle project of P.J. Wallis et al from the 1970s.

[41] I refer of course to A. and N.L. Clow, *The Chemical Revolution*, The Batchworth Press, London, 1952; A.E. Musson and E. Robinson, *Science and Technology in the Industrial Revolution*, Manchester University Press, Manchester, 1969; W.H.G. Armytage, *A Social History of Engineering,* Faber and Faber, London, 1961;; S. Pollard, *The Genesis of Modern Management, A Study of the Industrial Revolution in Great Britain*, Edward Arnold, London, 1965; Peter Mathias, *The Transformation of England,* Methuen, London, 1979.

character of the knowledge that they so ably and aptly discovered strewn across the cultural landscape of early industrialising Britain. They were not 'doing history of science', they were doing history. For reasons such as these, quite apart from the firm euro-centrism of so many uses of the term science[42], we are here most happy to treat of articulated knowledge, the URK of Gerry Martin. By URK we here mean that generally articulated knowledge that lies in close association with tacit and informal knowledge, the latter of which may well be generated experientially and through trade-skilling in apprenticeship[43] and so on.[44] It seems clear by

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[42] We must not confuse the two. For an extreme version of how the notion of Science might be so utilised to explain Europe, the Universe and Everything see the German physicist and Emeritus Professor of physics at Wolfson, Oxford, Kurt Mendelssohn: 'The white man's intellectual departure from the rest of the world had begun four centuries ago when, compelled by an unexplained impulse, he set out to explore the world around him … The West built better ships and forged more effective arms than the other great civilizations … Power production, even if they could not have developed it, was of course not beyond their comprehension, but they could never have formulated the concept of energy. It was a creation of Western thought for which the others utterly lacked the basis. Energy, its conservation, and the usefulness of the notion of conservation, were ideas that had grown out of more than two centuries natural philosophy. And this was a field of development in which none but the white man had participated. He had not withheld his ideas from others; they were just not interested, because the white man's way of thinking was alien and seemed of little meaning to them': *Science and Western Domination*, London, 1976, quote pp. 141-2. For nuanced wrestling with this sort of eurocentrism see Ian Inkster and Patrick O'Brien eds., Special Issue, The Steam Engine, *History of Technology,* 25, 2004, forthcoming.

[43] It should be recalled that it was not uncommon, perhaps especially in Britain, for apprenticeship schemes to be formally linked with educational charity foundations, such as that established with the legacy of Humphrey Chetham in 1651. Whether such foundations acted more as institutions of cheap labour supply than as systems of useful training is yet to be properly explored.

[44] Tacit knowledge obviously incorporates that which economists term know-how, 'evidenced by some form of physical matter [or] it may involve accumulated technical experience and skills which can best, or perhaps only, be communicated through the medium of personal services', see J. Creed and F. Bangs, 'Know-How Licensing and Capital Gains', *Patent, Trademark and Copyright Journal of Research and Education,* 93, 1960, pp. 4-17. Optimally for its inventor or owner, before such know-how can be protected by law it must have become in effect a trade secret. True know-how then is tacit knowledge that is secret and affords to its owner an opportunity to obtain a competitive advantage over those who do not possess it. Whether under such conditions the owner of know-how actually patents it will depend on the regulations of the patent system, the extent to which the basic URK is or might be known elsewhere, the value of the information to its owner or his competitors, the amount of money and effort and time already expended, the ease or difficulty [cost] with which the know-how could be efficiently acquired or duplicated by others. There may be a pre-patent phase

definition that the national industrial system that carried such a proximity within it was at a natural technological advantage over otherwise competing systems, particularly in the manner and frequency with which URK was 'brought to bear' on technique through reading, transposing, technical notation and spatial and graphic representations involving perspective and technical drawing..[45]

Patrick O'Brien, in necessary brevity, focuses in his ranging paper[46] on the differential development of reliable knowledge on the large level, but a historical key lies in the usage and diffusion of knowledge by competitive example and through a variety of information channels. Contra Gunder Frank, institutions are vital, if not quite in the manner expressed by Rosenberg and Birdzell.[47] As we have suggested, such 'channels' are not only those through which knowledge is presented in varied sites, but also ones through which knowledge is further articulated (by those other than its creators) and raised to acceptance as reliable and valid, as a test to be taken to the material world. Useful and Reliable Knowledge is not technical knowledge only, which is not technology. It is very difficult to isolate the 'practical, unregulated empiricism' of Musson and Robinson in Europe by the 18th Century. The dichotomy is false

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when the know-how is known by several and all of these are attempting to protect the know-how from others in the same trade or industry. Clearly, there are strong historical linkages between sites of endeavour, URK and know-how, and the institutional arrangements for the protection of intellectual property, and most of such relations have yet to be explored by historians.

[45] For a very good study of something similar to this for the U.S. see E.W. Stevens, *The Grammar of the Machine: Technical Literacy and Early Industrial Expansion in the United States*, New Haven, Yale University Press, 1995.

[46] Patrick O'Brien, 'Regimes for the Production and Diffusion of Useful and Reliable Knowledge in Western Europe and the Chinese Empire from the Accession of the Ming Dynasty to the First Opium War', a Provisional Paper for the 4th GEHN Conference, Leiden, September 2004.

[47] Nathan Rosenberg and L.E. Birdzell, *How the West Grew Rich. The Economic Transformation of the Industrial World,* London, 1986. For a critical analysis of how global historians have utilised notions of 'science and technology' in their large interpretations see Ian Inkster, 'Pursuing Big Books: Technological Change in Global History', *History of Technology,* 21, 2000, 233-54.

which excludes reliable knowledge from practical tinkering.[48] For this period and others we can not -

1) monitor knowledge-use, we may not identify the key use of reliable knowledge by an engine-wright except in the most unusual of instances;

2) and it seems highly probable that in all locations at all times into the present, an increased working competence spells a less-overt knowledge-use (blueprints were needed more in ignorant Russia than in knowing Belgium);

3) and possibly a reduced ability to articulate;

4) alongside the grasping of a more 'tacit' understanding. Increased working competence would surely mean less expression of codified and thus recorded 'knowledge', and an increased confidence and reliance on tacitly within such sites might render such knowledge less articulate.[49] With more and more normal working competence, previous experience generates in-built readinesses to notice or dismiss certain features of a complex situation or system as significant, and to judge them by criteria drawn from that

[48] See Francois Jacob, 'Evolution and Tinkering', *Science* 196, no. 4295, June 1977, pp. 1160-66, who makes a strong claim as to the association of creativity with new combinations, this to be a technical feature of patent legislations from the mid-19th century. See also the creative/combinational use made of this in Mokyr 2002 op.cit., p.225!

[49] For an argument concerning how tacit knowledge in large Japanese enterprises today might create a drag effect in decision making see Ian Inkster, *The Japanese Industrial Economy. Late Development and Cultural Causation,* Routledge, London, 2001, pp. 114-19.

experience. It is argued that this is perhaps especially so with physical craft skill.[50]

We may not escape this problem of the expansion of refractory evidence by reverting to 'technology as activity', for in its absolute form this means that we are forbidden the use of a phrase such as 'they had the technology but did not use it', and this would be too great a loss to historical analysis.

Reliable knowledge is not and was not simply new 'science'. Most recent global history rejects the idea that western science created western technique which created material advance, despite the early-Landes claims about 'ingenious applications of pure scientific principles to industrial needs'.[51] There seems to have been a later magic around 1870 which at last bound technique progress to advances in formal science.[52] There was nothing especially mysterious about the year 1870, but we certainly say that in the 1860s in Britain both steel making and chemicals now showed specific inputs from recent formal science. Henry Bessemer (1813-1898), William Siemens (1823-1883) and Sidney Gilchrist Thomas (1850-1885) between them possessed a contrasting mix of scientific training.[53] Their combined contributions of the air blast and manganese additions, the open-hearth process, and the use of a basic lining to the converter acted as breakthrough technological changes that led to a host of patented improvements in steam-driven machinery and machine tools 'and facilitated that increase in accuracy which made mass production

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[50] M. Polanyi, *Personal Knowledge*, Rutledge and Kegan Paul, London, 1958; Polanyi, *The Tacit Dimension*, Doubleday, New York, 1966; G. Vickers *The Art of Judgement,* Chapman and Hall London, 1965.
[51] David Landes, *Cambridge Economic History,* 1965, quote p. 550.
[52] See good accounts in Mokyr *Athena* op cit., pp. 85-104 and D.C. Mowery and N.Rosenberg, *Technology and the Pursuit of Economic Growth*, Cambridge University Press, 1989.
[53] See in particular Gilchrist Thomas, *Memoirs and Letters of Gilchrist Thomas*, John Murray, London, 1891

possible'.[54] Again, the chemical industry after mid-century rested more on new science applications and upon electrical engineering, which together allowed greater explanations of manufacturing processes and then yielded many patented applications to telegraphy, light and power. It was possibly changes in the URK-technology relationship in organic chemistry more generally that allowed the swift German advance there, followed by continued gains in that nation in the application of the principles of physical chemistry to inorganic processes.[55]

However, we repeat that reliable knowledge is rarely if ever new science.[56] The history of the west has rarely demonstrated the direct linkage of a eureka scientific advance with a paradigm-shifting technological turn of the screw, and much has been made of this by all recent globalists, for it is one further step away from an older euro-centricism - once we accept a 'western' privileging of science as 'of Europe' and 'for Europe'. But we are in a land of straw dogs and red herrings, an unhappy place. History does demonstrate - and the 18th Century sees particular demonstrations of - the technical problems of the material world yielding to the applications of reliable knowledge.

We now have in place some building blocks. Is there a valid empirical case in the following claim? Socio-spatial proximity of URK and technique was an asset to early industrialising systems and was found in Europe to a far greater extend and over far greater numbers of human

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[54]C.F. Carter and B.R. Williams, *Investment in Innovation*, Oxford University Press, Oxford, 1958, quote p. 8.
[55] Sherwood Taylor, *A History of Industrial Chemistry,* Heinemann, London, 1957; Jewkes, Sawers and Stillerman, *The Sources of Invention,* Macmillan, London, 1958.
[56] It may even have been quite often the case that URK did not depend on science that was new and somehow 'true'. That is, prescriptions that resulted in real artefacts or working processes could be forged out of 'scientific' explanations that were later found to be false, even nonsensical. For a range of points relating to this see the important papers by Arnold Thackray 'Science and Technology in the Industrial revolution', History of Science, 9 (1970), pp. 27-63, and Robert Fox, 'Science, Practice and Innovation in the Age of Natural Dyes, 1750-1860', in M. Berg and K. Bruland eds., *Technological Revolutions in Europe,* Edward Elgar, Cheltenham, 1998, pp. 86-95.

agents, connections, and associations than in any other earthly place by the mid-18th century and possibly somewhat earlier. The industrial world forged ahead in Europe not because that part of the world had a monopoly of ingenuity and novel ideas and the philosophies to commend and multiply them. This is entirely doubtful. Elements of euro-machinery can be found elsewhere, similar items of ideology may be found across the globe, disputes may go on indefinitely about degrees of identity and whether parts added up make a necessary whole.[57] The European material world forged ahead because it possessed so much more in the way of the new ideas and knowledge packages being located in places where the search for technique was developing among a greater number of individuals than Anywhere Else. Material victory was primarily a matter of socio-cultural statistics[58], and these could not be easily matched or emulated by any other social system however liberal the regime or intelligent the artisan.[59]

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[57] One of the problems of the classic Needham paper on the steam engine is that although elements of the Newcomen engine may be discovered in China or elsewhere at earlier dates, this is not to say that a working steam engine was somehow to be forthcoming – the absence of overall conceptions or of an essential ingredient amongst the many ancillary elements might at all times inhibit the production of the whole – for examples and statements of which see papers by Sivin, Deng, Inkster and others in Special Issue; The Steam Engine, *History of Technology,* 25, 2004, forthcoming, eds. Inkster and Patrick O'Brien. For Needham's essay see .. Naquin and Rawski uncover many dynamic changes in eighteenth century china including commercialisation new mobilities and urbanisation, major uprising and rebellions prior to the Opium Wars, together with intellectual changes, but do not associate them with an increase in technological innovation or the emergence of new methods and products, whilst emphasising the 'borrowing' of the Chinese technologies of porcelain, silk and tea manufacture by Europeans, see Naquin and Rawski op.cit. throughout and eg., p. 233, and Inkster, in Porter op. cit.

[58] More broadly, when Adshead (op. cit. footnote 4) differentiates potential information from actual information, he is thinking of the differential historical power of 'number and concentration … a more populous area will contain more potential information than a less populous … Potential information has a spatial aspect'(p. 174). See below footnote and my emphasis on sites and neighbourhoods, but I would emphasise the testing alterations that occur to knowledge as it passes from potential to actuality, as well as the importance of the exact social character of the 'concentration'.

[59] This way of putting the problem does not seem a long way off Mokyr's distinction between propositional knowledge [that which forms the knowledge environs of URK and to this extent represents material feasibilities, but contains much else besides] and

It remains to expand a little on these somewhat stylised relationships and introduce some How questions for the watershed period of the 18th Century and into the 1830s, from which point the new Machinofacture grew to dominate industrial modernisation and maintained its central position in world history to circa 1971 – another story about useful and reliable knowledge.

5. URK Beyond the Academy and the question of How the British?

The 18th century witnessed technological innovation throughout advanced sites in Europe, but from around the 1730s England in particular became a centre of knowledge inflows, innovation in manufacturing machine tools and devices, new materials and energy production. These were associated with lagged diffusion and challenge and response e.g., Kay's loom in cotton to Hargreave's spinning jenny, which encouraged Arkwright's water-frame into use, the bulkiness of which stimulated centralised power systems thence improvements in Newcomen and Savery engines etc. The theory of the long-term must not suppose that demands always increase supplies of given products -

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prescriptive knowledge involving 'a set of instructions that determines what this economy can do' (p. 16). From the resulting sets of blueprints/prescriptions, 'a few are selected for actual execution'. Here I am suggesting that the more propositional knowledge then the more URK; the more URK is associated with socially and geographically open sites the more it moves, is honed, and has greater chance of being selected by a potential user/querist; the more there are such querists the more likely they are exposed to commercial imperatives that induce a move from blueprint to innovation or experimental production. Note that this approach allows a fair amount of *ceteris paribus* but does not require a linear move from some sort of pure knowledge to some sort of artefact or process. Querists and their audiences are social fractiles, particularly prior to the twentieth century. See Joel Mokyr, *The Gifts of Athena. Historical Origins of the Knowledge Economy,* PUP, Princeton, 2002, especially chapters 1-3. For an earlier approach to the distinctions and the idea of mapping see his essays 'Knowledge, Technology and Economic Growth in the Industrial revolution' in Bart van Ark, Simon K. Kuipers and G.H. Kuper, eds., *Productivity, Technology and Economic Growth,* Kluwer Academic Publishers, Boston, 2000 and 'Evolutionary Phenomena in Technological Change' in Ziman, *Technological Innovation* op. cit., 2000, pp. 52-65.

they may also increase prices, induce imports or product innovation. But where there is a plentiful and proximate supply of reliable knowledge then process and product innovations are more likely to be the combined effective response. In Britain, technical innovation was associated with institutional innovation, much of which required statist actions - parliamentary enclosures for turnpikes, canals and so on. It is certainly possible to posit that institutional resources were more of a constraint on growth in England than, say, capital resources around 1650, and that institutional innovation was thus a more dynamic element in 18thc material progress than was capital accumulation.[60] We would maintain that the best in the west was characterised by wide-ranging institutional innovations, more or less linked to the articulation and diffusion of reliable knowledge, commercial openness and a diverse urbanism. This was the new set of forces that joined the particularities of 'Smithian growth' in Britain to forge a conjuncture that we at times call the Industrial Revolution.

We can provide a sketch towards How through 9 Rubrics. It should be noted that these do address Patrick O'Brien's notion of 'regimes of URK', as at one point he depicts such regimes as composed of 'urban sites, legal systems, institutions, incentives, patronage and above [all] the

[60] We are here suggesting that the scarcity of appropriate institutions might be treated in the manner that economists treat a scarcity of labour or capital. If any such physical factor imposes a constraint on an industry or economy, then the loosening of that constraint by greater supplies (from wherever) of such a physical factor will cause or allow growth to occur. We may apply this by analogy to institutional rigidity, which in terms of institutionalised functions may be see as representing a zero-change in supply – a multiplication of unchanging institutions in a non-utopian world is equivalent to continued overinvestment in low productive industries . If indeed, 'institutions' rigidity is an important reason why institutions may heavily condition and sometimes inhibit the development of human societies' (Landesmann and Pagano),then *growth of new* more flexible or unusually 'plastic' (Paul David) institutions may, in short, be seen as a cause of more general material growth in, say, 18th and 19th century Britain. For the quote above see M.A. Landesmann and U. Pagano, 'Institutions and Economic Change', *Structural Change and Economic Dynamics,* 5, no. 2 (December 1994), pp. 199-205, p. 201 and for more general and incisive analysis see Paul David, 'Why are Institutions the 'Carriers of History'? Path Dependence and the Evolution of Conventions, Organizations and Institutions' in ibid. pp. 205-220, see p. 218.

cosmological assumptions and styles of investigation'.[61] The list below encompasses all of these but a comment should be added. All aspects of legal systems that protected markets and private property are of relevance, and for 18th century Britain an outstanding feature was protection of intellectual property rights. Institutions are those beyond the market place, and here they centre on associations and sites of URK creation, application and diffusion. In Britain incentives were as in the rest of advanced Europe, but possibly stronger than elsewhere in terms of the social rewards to intellectual and material success. Finally, more than anywhere else, Britain during the 1780s witnesses patronage shifting from that bestowed by great individuals, houses and gardens or royal societies or the state to that offered by large urban audiences for lectures, demonstrations, publications and cheap editions, classes, equipment auctions and raffles, collections, exhibitions and displays.[62] As to styles of investigation, these were possibly all-but euro-wide, and in analyses of the material advancement of Britain specifically, it might be better to focus on matters of the socio-geographical situating of such styles.

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[61] O'Brien op. cit. ftn. 20, quote p. 5. We also agree wholeheartedly with the notion that comparative and global history considerations of the role of URK in material progress or retardation should fasten on to the character and strength of such regimes rather than continue to dwell upon the often dubious and intangible distinctions between the intellectual histories of total national or 'civilization' systems.

[62] A main point here being that there was and is such a thing as a tyranny of benefactors. State income, contracting and guaranteeing may of course be large and regular, just as that of the 'audience' might be slight and tenuous, but the support of the latter is the more likely to forge an expanding URK through challenge, adaptation and response mechanisms of many kinds. This is not far from Hume who believed with many of the early-moderns that the fine arts and philosophy thrived under princes, the sciences and arts under republics, and we might add here that princes could be highly volatile in their gestures of support – for every Henry the Navigator there were a multitude of Athenians, they who (Swift and other Enlightened figures emphasised) impeached Miltiades, Aristides, Themistocles, Pericles and Alcibiades. The historical relations of patterns of patronage and styles of thinking/investigation have yet to be examined.

I. Mechanisms of spread of URK

London was perhaps the greatest inducting city known in Europe, swallowing skilled migrants, spawning civic places, shortening the avenues of acceptance, multiplying the marks of success. But the English provinces were greater assets - so William Hutton entering Birmingham for the first time in 1741, where individuals possessed 'a vivacity I have never beheld; I had been among dreamers but now I saw men awake. Their very step along the street showed alacrity: Every man seemed to know and prosecute his own affairs: The town was large, and full of inhabitants and those inhabitants full of industry'.[63]

II. Sites of URK.

In Britain such sites moved well beyond the Royal Society of Arts and Manufactures or the Manchester LPS or even the Lunar Society. The falling relative price of URK especially in the 1780s to circa 1830s period suggests that URK was oversupplied, and then this was followed by the second boost in the falling price of an improved URK after 1851 with the new patent legislation [North America possibly reaping this effect with the patent system reforms in the 1830s[64], but note Brougham's Act of 1835 in

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[63] William Hutton, *An History of Birmingham to the Year 1780*, Birmingham, 1781, quote p. 63.

[64] I refer here to the change in US patent law by the act of 1836 which brought in novelty requirements. Under the urgings of George Washington himself, the first Congress enacted the first American patent act in 1790, modified 1793 – under it there was no examination for novelty and some 10,000 patents were issued for terms of 14 years. In 1837 the US Commissioner was noting that the lower number of patents in that year (435 issues) 'is to be attributed chiefly to the operation of the new law, which subjects all applications for patents to a careful examination as to the originality of the invention claimed', *Report of the US Commissioner of Patents, 17 January 1838, 25th Congress, Doc No. 112 House of Representatives,* Washington, Thomas Allen, 1838, quote p.1. This followed also a major fire of December 1836 that destroyed models and documents and tended to clear the system of redundant patents – patentees only bothered to re-register patents with destroyed documentation in cases of commercially viable inventions. It must be noted that no such institution was ever perfectly formed – thus by 1850 the US Supreme Court in *Hotchkiss v Greenwood* approved the trial judge's decision that 'if no more ingenuity or skill was required to construct the patented invention than was possessed by an ordinary mechanic acquainted with the

Britain]. The resources that produced URK were not costed fully by markets, nor by interests, nor by the British state.

III. URK and the Open Society 1 [a la Habermas[65]]

That is, the world of debate, test, search, trust. Under what local or other conditions does the ‘good life’ (Aristotle’s urbanity above) naturally incorporate reliable knowledge? The coffee-house was not important primarily because of the lectures or the demonstrations that occasionally took place, but because it was one public space in which strangers became friends, where outsiders could become good citizens.

IV. URK and the Open Society 2 [a la Hume]

‘Every improvement which we have made, has arisen from our imitation of foreigners; and we ought so far to esteem it happy, that they have previously made advances in art and ingenuity. But this intercourse is still upheld to our great advantage: notwithstanding the advanced state of our manufactures, we daily adopt, in every art, the inventions and improvements of our neighbours. The commodity is first imported from abroad, to our great discontent, while we imagine that it drains us of our money: afterwards, the art itself is gradually imported, to our visible advantage; yet we continue still to repine, that our neighbours should possess any art, industry, and invention; forgetting that, had they not first instructed us, we should have been at present barbarian; and did they not still continue their instructions,

business, then the patent was invalid’, and could thus be infringed by competitors. This absurdity arose from the perversion of a more reasonable [earlier and later] British format, where judges had argued that a patent specification should be clear and forthright enough that any competent mechanic in the trade could construct or manufacture by it. This of course, was quite another matter. For background see Giles S. Rich, ‘The Vague Concept of Invention as Replaced by Sec. 103 of the 1952 Patent Act’, *Journal of the Patent Office Society,* XLVI, no. 12, December 1964, pp. 855-76.

[65] J. Habermas, *The Structural Transformation of the Public Sphere,* [1962], trans. Thomas Burger with the assistance of Frederick Lawrence, Polity Press, Cambridge, 1989.

the arts must fall into a state of languor, and lose that emulation and novelty which contribute so much to their advancement.' [66]

Strangers and their goods bring artefacts and ideas. It is very well worth noting Hume's juxtaposition of emulation and novelty – in contrast to some of the more simple-minded of intellectual historians, Hume saw that increments of creativity followed from processes of imitation, emulation and absorption. The two were not distinct processes operating on different planes amongst contrasting folk. Rather, the latter processes depended on the cultural norms of open communities within which lose ties encouraged the flow and critical adaptation of URK.[67]

V. URK Dynamics and Phraseology.

Generations and regenerations of URK associations and sites, from elites to common men.

During the years1780-1800s the mainly metropolitan, gentlemanly associations gave way to a much greater provincial movement. The representative associations had been the Royal Society of Arts in London, the Manchester Literary and Philosophical Society [1781], the Manchester College of Arts and Science [1783], or the Lunar Society of Birmingham. The most important distinguishing feature from the 1780s was the rapid rise in the numbers engaged in URK pursuits and associations, added to by the flood of science-medicine trained graduates from Scotland into London and the major urban centres, a ferment of knowledge that fused speculations concerning political philosophy with those concerning experimental philosophy (Joseph Priestly of

[66] David Hume, 'On the Jealousy of Trade' in *Essays, Moral Political and Literary,* Edinburgh, 1752, quote p. 335.

[67] Here we might reflect upon the futility of distinguishing creativity from copying, or the creativity of the Chinese versus that of the Islamic world or of the Atlantic. Spotting creative texts or theories or even applications in varying civilizations at different times is an interesting aspect of the intellectual history of the globe, but given the Hume position, it may never say much about its material history.

Birmingham being the commanding figure), a decided movement towards a provincial, urban ascendancy of the URK culture. The early 19th provincial movement was far more socially inclusive and distinctly more local and industrial than the previous radical-dissenting associations. Lectures and discussions moved from and between natural and experimental philosophy and 'development and explanation of the various processes employed in different branches of manufactures and the Arts',[68] or did so somewhat more formally when 'theory will be illustrated by application to the most useful of the chemical and mechanical arts'.[69]

The 1820s-30s steam decades, dominated by early machinofacture and the pursuits of the mechanics. The alliance of artisans and engineers at the beginning of what we might dub the 'Rosenberg transition' – wherein innovation based on artisanal, industry-specific sites gives way to the innovation complexes of the capital goods industries, dominated by engineers. This process is in fact gradual, taking place in Britain over the years circa 1830-1870, with engineers leading in broadly process and machine-tool innovations, artisans remaining dominant in product innovation. In these years the activists and audience for URK reach very large numbers, many innovator/patentees and manufacturers are now amongst the lecturers, writers and discussants, and theorising in an area such as hydraulics would automatically elide with examples of and experiments on 'Barker's Mill, Water Wheels, Bramah's Press, Water Ram, Hydraulic Engine'.[70]

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[68] Thus William Higgins in his 40-lecture course at the Elaboratory of the Dublin Society, where he was Professor of Chemistry and Mineralogy; *The Dublin Evening Post*, 16 January, 1798.
[69] Thus John Webster during his lecture tour of southern England; *Salisbury and Winchester Journal,* 11 July 1808, 6, 15 November 1813.
[70] In this case, John Sissons in Sheffield in 1841; *Reports of the Sheffield Mechanics' Institute,* 8, 1841, p. 4; Ms material relating to Sheffield Mechanics' Institute, SLA, MD., 1985c, handbills 1841.

1850s onwards – the British, American and to a lesser extent the French[71] patent systems emerge more truly as information systems and the engineers rise to dominance within them. In this period the mechanics' institutes and other associations of engineers and skilled workers regularly acted as sites where URK was exhaustively presented, discussed and disseminated at a very high level.[72] By this time throughout the British [not merely English] provinces most public libraries and mechanics' institutes possessed as much in the way of patent specifications and abridgements as they did general works on science and the arts – thus by 1867 the museum and library at Salford possessed patent material and science-technical literature in the ratio 2:3.5.[73]

From the 1870s there are serious and very vocal attempts at the formalisation of British URK in the face of supposed industrial competition – thus the rhetorical industry that arose out of the Paris Exhibition of 1867.

[71] See Liliane .. opcit, and the earlier treatment in chapter XII and elsewhere of Shelby T. McCoy, *French Inventors of the Eighteenth Century,* University of Kentucky Press, Kernell Press, 1952. The French instituted a more formal patent system in 1791, parallel to the USA after a long period of privileges. By it novelty was limited to France (that is any imported tool or machine not used in France was counted novel and the importer the inventor), entitlement was electively up to 15 years, and infringements would be allowed or the patent voided if the invention was not put to use within 2 years or when the patent description was deemed insufficient. Patent systems more or less similar to those of Britain or France were adopted in Prussia in 1815, Belgium 1817, Austria 1820, Zollverein members 1842, and then a greater spread during the following decade.

[72] For fine examples of which see the lectures to the Manchester, Leeds and other institutes addressed by William Fairbairn to all working engineers from 1852, and published as *Useful Information for Engineers being a Series of Lectures delivered to the Working Engineers of Yorkshire and Lancashire,* Longmans, London, 1856. These not only presented the established findings and machinery of a considerable period of improvement, but incorporated considered applications of very recent experiments and claims by Joule, Thompson and Regnault, recent innovations in high pressure-steam mechanics, and a series of experiments on boilers and explosions as appendices covering pages 247-376 in which a mass of new machinery is scrutinised.

[73] Fairbairn op cit., p. xiv.

VI. URK and the Undifferentiated Sci-Tech.

In later 18th century Britain there was a complete failure to recognise the distinction between something called 'science' and something called 'technique' in the contemporary culture of diffusion, transfer, testing, replication and application.[74] The distinction tended to be a Creators' Story a la Watt, about need of the science before or alongside the technology. Even here, familiarity bred contempt – thus the 'scientific knowledge' of latent heat was communicated to Watt, was manifestly mentioned and utilised, but soon Watt stopped 'overtly using' such a term of reference as it became part of his tacit understanding of the specific technical problem. However salient and however constructed in cases of creation, patent documents and discussion societies regularly were blinded by the light and could not spot the differences or the supposed linearities [from science to technology] involved. Savant societies honoured engineers as a matter of course – Smeaton, who was known primarily through his experiments on water-wheels for turning mills made during 1752-3, was then elected FRS at the age of 30 and a little later was awarded the society's gold medal. It was common enough for the same person to be both URK creator and machinist or technologist. In his Treatise on Mills of 1861-63, William Fairbairn wrote of these early years of the 'itinerant engineer and mechanic of high reputation', that even the ordinary millwright was 'a fair arithmetician, knew something of geometry, levelling and mensuration. He could calculate the velocities, strength and power of machines; could draw in plan and section',[75] this certainly true of Smeaton, Telford, Ewart, Maudslay, Bramah and Rennie, all engineers

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[74] For the example of a completely representative figure who would have been utterly perplexed by the maintenance of such a distinction see Ian Inkster and Maureen Bryson, *Industrial Man: The Life and Works of Charles Sylvester,* Jackpot Books, Las Vegas, 1999.

[75] William Fairbairn, *Treatise on Mills and Millwork*, London, 1861-63 and many editions, quote from 4th edition 1878, p. x. He went on to add that 'Living in a more primitive state of society than ourselves, there probably never existed a more useful and independent class of men than the country millwrights'.

who played an important part in both the creation and the diffusion of advanced technologies into the 19th century. Men such as T.C. Hewes the Manchester engineer, were major exponents of the natural and experimental philosophies, but he also built water wheels all over the country and invented the suspension wheel. The links between knowledge and applications were forged of complicated interrelationships between scientists, engineers and mechanicians in a fairly fluid, competitive environ. Thus so with the development of the Scheele-Bertholet chemistry of chlorine bleaching, discovered in 1785, published in the main in Nicholson's Journal in 1787. In that same year James Watt received a demonstration of the method and 'instantly grasped the commercial possibilities of the process' and then received a letter from his father-in-law, the Glaswegian bleacher William Macgregor, whom he had already introduced to the process and who now wanted commercial return for his own efforts,

> "at the trouble Expence and risque of making under your direction the Experiments in the Great so as to ascertain the Value of the discovery …I have therefore better hopes than I formerly had of the liquids answering upon a large Scale and now only wish to have the inventor's permission and your directions to try it in the great by which I will be much better able to judge whether it will be an object worth your attention and mine or not [if so] I should be equally concerned in the manufacture and sale of the liquid [and] … to bring in the inventor for a third share".

As Watt was then writing to Boulton of 'some French men that are come to Liverpool and Manchester to teach the new Art of Bleaching and mean to take out a patent', it is clear that this is just one example of the multitude of avenues[76] whereby URK somehow became technique – by February 1788 Macgregor was whitening some 1,500 yards of linen by the new process in competition with several other firms.[77]

VII. URK and the British State – from awards to property rights.

Amongst all European others, here was a state that embraced self-interest and , in the words of Otto Mayr, nurtured this as a source of energy itself, 'that motivated initiative, enterprise and innovation – a quality that the state should tolerate within the normal laws, without restriction and regulation', and in such a formulation we can see the close connections with the positions of Hume and Jacob.[78] In a state where the imagery of self-regulation was so very powerful, and in the context of authoritarian regimes elsewhere, there was greater likelihood of self-regulatory mechanical devices becoming 'part of the standard practice of British millwrights', and thus the series of British patents and the steam-engine governor of the 1780s. Mayr's thesis is that in Britain more than elsewhere self-regulation as an abstract concept in polity and state preceded its general recognition in the world of material technique.[79]

As in Edmund Burke's aphorism that 'a law against property is a law against industry', any 18th century state that strengthened property rights in technical innovations promoted industry like no other, and in this respect the British state was ahead of all others until the 1830s and

[76] For the avenues in Liverpool itself see the many instances given throughout the volumes of the *Quarterly Journal of Science*, whose editor James Samuelson lived in the city.
[77] In fact the process was probably inhibited by its negative health impacts on workmen, and greater usage awaited Charles Tennant's invention of bleaching powder in 1799, which required the addition of slaked lime.
[78] Otto Mayr, *Authority, Liberty and Automatic Machinery in Early Modern Europe,* Baltimore, 1986, quote p. 165. In Hume's essay 'On the Balance of Trade' [op cit Hume p.255] self-regulation, liberalism and property are intimately linked, although as in my rubric 4 above, the essay 'On the Jealousy of Trade' points out that diminishing returns will set in to even this combination unless foreign trade and intercourse was sufficient to induce learning processes and transfers of knowledge and techniques.
[79] Ibid., pp. 188, 194, 196-8.

possibly beyond, and again we might properly see this as some measure of advanced liberalism and an ideology of self-regulation.

VIII. Sites and Numbers – from associations to urban cultures and the Steam Decade.

Rather than looking in Britain or elsewhere for extraordinary meetings or advancements, it might be better to pursue the Musson-Robinson tack of establishing the variety and number of the sites of URK. Where they tended to concentrate on the 18th century broadly, the sense of things at present would be to investigate in depth the years circa 1780-1830/40, which appears to be a key period when Britain is differentiated from mainland Europe on several levels, including those of relative lack of socio-political disturbance, the spread of the steam economy, and accelerations of industrial and economic growth associated with the early years of machinofacture. The work that has been done on this to date seems to suggest that no other nation possessed so varied and many sites of URK associated with thriving urban provincialism.[80]

IX. In an Open Euro-System.

With 2-way transfers of certain levels of URK a commonplace, and unstoppable by war or law, why did not URK arrive at all euro-places with merely a Cook's Tour travel-lag to explain? Why was it not applied in similar ways in several systems? Why did not Britain face more competition prior to circa the 1830s?

Indeed we might accept the importance of a range of more conventional supply [investment funds] and demand [of consumers for products, of other producers for machine inputs etc] elements in explaining the subsequent dominance of Britain within Europe for at least

[80] Ian Inkster and Jack Morrell eds., *Metropolis and Province,* Hutchinson, London, 1983.

a few decades. Williamson, Pollard, and others described features of advanced regions and resource areas, and the lags involved in backwash and catch-up, and many others have followed.[81] Whether this work has adequately explained continued advancement of regions proximately connected to laggards is yet a matter of debate. But for the years prior to circa 1830, we do suggest that whilst some of the superstructure of URK could travel, be stolen or mislaid, migrate with skilled populations, be carried by the machinery of war, be induced by ambitious governments and so on, the noise of all this activity should not lead us to suppose that the sub-structure of a complete advanced conjuncture was so transferable or replicable. European and Atlantic industrialisation was surely more than contingently associated with either or both of an invention of institutions that substituted for the British assets that I have sketched in the above rubrics, or a move of technologies away from early machinofacture towards the later stages associated with Bessemer steel, inorganic chemistry and electro-mechanism.[82] Either of or both of these processes required time, and seem only to have taken accelerated effect from around 1870. Those who were proximate enough in geographical or commercial terms to benefit from one or both of these new elements had taken advantage of them by the end of our period.

This section when filled out should get a longer and precise summary of position on uk.

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[81] See for instance J.G. Williamson, 'Regional Inequality and National Development', in J. Friedmann and W. Alonso eds., *Regional Policy: Readings in Theory and Application*, Cambridge., Mass, 1975, pp. 158-200; Sidney Pollard, *Peaceful Conquest,* OUP, 1981. See however the insightful and important qualifications and specifications in Pollard, *Marginal Europe. The Contribution of Marginal lands Since the Middle Ages,* Clarendon Press, Oxford, 1997, especially chapters 1, 3-5.

[82] Thus the standard British (early starter/lagging institutions) to German [later starter/novelty of modernised institutions] contrast, for modifications and sophistications of which see the outstanding contribution of Sidney Pollard, *Britain's Prime and Britain's Decline, The British Economy 1870-1914,* Edward Arnold, London, 1989, especially but not only chapter 3.

6. Poised for Machinofacture – End Games of the Coming Domination 1830-1912.

Patrick O'Brien has concluded from the recent work on growth rates, that 'the First Industrial Revolution as a widely diffused national event does not come on stream until well into the nineteenth century', and we are quite prepared to take this notion on board.[83] Advancement in British growth rates seems clear enough during the 1830s, and this happily coincides with the firm movement of industrial technological change towards machinofacture.[84] William Fairbairn captured our meaning of this term when in 1861 he noted how everything 'is now done by machine tools with a degree of accuracy which the unaided hand could never accomplish'. As the first generation of toolmakers such as John Wilkinson or Henry Maudslay gave way to the second generation dominated by such men as Richard Roberts and Joseph Whitworth, they did more than pave the way for great breakthroughs in dyestuffs, steel production, locomotion, telegraphy, improved motive power and the use of new materials. Such breakthroughs from mid-century are highpoints

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[83] Patrick Karl O'Brien, 'Endogenous and Exogenous Technological Progress. Macro Inventors and Macro Inventions in the English Cotton Textile Industry from John Kay to Edmund Cartwright', draft of a presentation for the conference The Penrosian Legacy, INSEAD, 11-12 May 2001. See also Crafts op. cit p. 198, where an annual growth rate of GDP is given for 1831-73 as 2.4% as compared to 1.9% for 1801-31 and 1.3% for 1780-1801. In terms of estimates of TPF the distinctions are even greater, with the annual figure of growth for 1831-73 given as 0.8, twice that for 1801-31, 8 times that for 1780-1801; see also N.F.R. Crafts and C.K. Harley, 'Output Growth and the British Industrial Revolution: A Restatement of the Crafts-Harley View', *Economic History Review,* 45, 1992, pp. 703-30.

[84] The term has a classic status, as used by Marx in *Kapital* vol 1 pp. 389f ; J.S. Mill *Principles,* in Silver Library Edition e.g. p 26; Toynbee in 1884; Landes *Unbound Prometheus* pp 104 forwards; for a good example of the technical detail see the forthcoming paper by Richard Hills on Richard Roberts in *History of Technology.* My own temptation as an historian of technology across a broad spectrum of systems is to recognise the quality and quantity distinctions at work and refer to the years 1780-1830 as those of Industrial Revolution [associated with low rates of overall growth and heroic inventions yet to be applied or adapted through incremental innovations and adoptions] and those circa 1830-1870 as ones of early Machinofacture [where the latter processes have affected overall growth through measurable improvements of TFP], with the years 1870-1971 representing the later phases of Machinofacture.

within a great stream of machinofacture, one which defined the underlying modernity of the Victorian production system. Patents marked the advances[85] – even prior to 1850 these included the turret lathe and cylindrical grinder, Whitworth's standard screw thread and improved planer, Nasmyth's steam hammer and shaper plane, Fairbairn's riveting machine for the Lancashire boiler, and Siemen's differential governor. These gave rise to the subsequent host of machinofacture patents in Britain and into Britain from elsewhere. Most leading engineers were now routinely patenting their complete portfolio of improvements – thus Fairbairn patented the riveting machine in 1837 in the name of his assistant engineer Robert Smith, a direct acting, parallel-motion marine engine in 1841, his improvement in vessel riveting by thicker rolling of plate edges in 1842, the two-flued boiler in 1844 in the names of himself and another engineer, John Hetherington, an application of Robert Stephenson's wrought-iron girder bridges (tubular bridges) and for improvements in driving the screw propeller, both in 1846, and for tubular cranes in 1850.[86] It is notable that such a clutch of inventions included minor and major applications, novel applications and novel principles, as well as partnerships forged of what appear to have been genuine shared energies and inputs.[87] This was the era of basic applications of true flat

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[85] It should be emphasised that this can not generally be said for any nation prior to the 1830s because of lack of novelty clauses, examination or search procedures until the reforms of the 1830s and the adoption of patenting by a greater number of nations in the 1840s. Thus in the US during the 1820s a defendant in a patent case of infringement was not allowed to even give evidence that the patent infringed was not new, 'nor can that circumstance, however apparent, be judicially noticed by the jury', as shown in a landmark case, Kneass vs Schuylkill Bank, October 1820: see *Public Acts of Congress relating to Patents, Digest of Decisions under the Same Made in the Courts of the United States, January 1831*, Department of State Doc No. 50, Department of State, Washington, 1831, quote p. 30. For good studies of patent systems see the Special Issue of *Technology and Culture*, 32, no.4 October 1991, and more recently the Special Issue of *History of Technology*, 24 (2002).
[86] William Pole, *The Life of Sir William Fairbairn,* London, Longmans, Green and Co., 1877, see pp. 164, 182, 212, 258, 320, 338.
[87] Thus Robert Smith was a very skilled machinist who had worked in the area of the 1837 patent for some time (eg., his patent of 22 June 1836) but as a former manager of

and cylindrical surfaces, of planing tools, lathes, measuring tools and devices, the universal milling machine and die stamping, of the standardized screw thread and the machine processes of fixing, sliding, turning and relocating. Incremental efficiency increases[88] were the bases of Victorian engineering and industrial growth and this is directly measured in the great increase of patent registrations[89] based on the new machining – during the transition years of 1842-61 some 24,000 patents were granted in Britain, this compared to the highest decadal figure for

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the Manchester works had gained enough to forward some £3,000 into Fairbairn's Millwall works. John Hetherington brought out a series of patents in the years 1844-1855 concerning furnaces for stationary steam boilers, textile machinery and parts (reels, combing and doubling equipment, flyers) , machine tools and pipe-casting, that together were to provide the foundation for a major nineteenth century engineering firm.

[88] We still need a formal study of patterns of incrementalism flowing from major inventions. Most, however, were well enough known by earlier industrial historians, if somewhat ignored by subsequent analysts. A good example of a chain of improvements that allowed lower cost and wider range of applications were those following the first crude Cartwright/Jeffray-type weaving machine (1786-1792), such as the introduction of the protector allowing direct action of the motive power (Robert Millar patented 1796), the improvements on this by the 'Stockport-group' of Radcliffe, Ross, Johnson and Horrocks, dressing and sizeing by power, which additions may have been responsible for the time-lagged increase in the number of power looms in operation after 1815. By the 1860s, the loom that now powered the much faster growth of industry incorporated the important improvements of John Ramsbottom and Richard Holt (patent 1834), William Kenworthy and James Bullough (patented 1841-2, all for detection and prevention of breakages), John Railton (patent 1842) and John Elce and John Bond (patent 1852, these together improving cloth stretching), John Sellers (1845 patent, which allowed instant stoppage of fast-reed looms), all of which provided the truly self-acting character of the mid-century product. Which of these 15 men (and we could add several more) is the 'hero' - the one who 'started' this chain of improvement and URK-reasoning, or any of those who brought the principle to efficient practice as a fundamental ingredient of higher industrial efficiency and growth?

[89] Analysing patents granted in Britain after 1855 shows the majority [63.1%] to be located amongst the 6 leading machinofacture categories of general machine engineering (16.3), transport including locomotives (9.8), building , construction and haulage (9.2), textile processes (8.4), metal fabrications and processes(12.8,), and motive power and fuel. Within these the largest sub-categories patented were cutting and working metals, bearings and lubrication, mechanism and mill gearing; railway and tramway vehicles, shipping, locomotives, railways and tramways, signalling and communicating; building and structures, lifting and hauling, cements and composites; spinning, weaving and woven fabrics, bleaching and dyeing, drying and separating; steam engines, steam generators, manufacture of fuel; furnaces and kilns, lamps, nails, rivets and bolts, cutlery, printing and letter-press.

the period 1689-1829 of 1,355 for the 1820s. [90] The great majority of the new mass of incremental machinofacture patents lodged in Britain from that time (amounting to around 75% of the total of 317,665 registrations for the years 1855-1903) were taken out by either engineers, or artisan-tradesmen or combinations of engineers and tradesmen, and some quarter or more of these represented lodgements into Britain from overseas.[91] More precisely, where artisan/tradesmen dominated still in the years 1830-1850, from then engineer-patentees began to predominate, especially so in machinofacture process innovations.[92]

From all of this we might hazard a comparative generalisation. In contrast to its best-case industrial contenders, in Britain the artisan workshop culture generated a very lively and creative innovative technological system throughout the years to 1914. But in Britain - in contrast to a nation such as France - this culture was closely associated with a provincial, urban associative culture that diffused and tested and applied reliable knowledge. This distinction, if it may be maintained, is probably true for the later 18th century, but especially applicable to the years from about 1820 to around the 1860s. The notion that modern industrialization might have been delayed in a contender such as France because of the continued predominance of artisan production as such is almost certainly incorrect. However, in comparison with Britain, France might well have suffered through a disassociation of artisan skills and organisations from those of industry and urbanity more generally, and this

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[90] For details and sources see Ian Inkster, 'Technology Transfer in the Great Climacteric. Machinofacture and International Patenting in World Development circa 1850-1914', *History of Technology*, 21, 1999, pp. 87-106.

[91] For sources and details of the engineer take-over of patenting in Britain see Ian Inkster, 'Machinofacture and Technical Change – The Patent Evidence' in Inkster et al, *The Golden Age. Essays in British Social and Economic History, 1850-1870*, Ashgate, London, 2000, pp. 121-142.

[92] Prior to the 1850s engineers were far more active in the leading process areas. Thus of 330 steam engine patents for 1801-30 almost all were registered by engineers. See appendix listings in Elijah Galloway, *History and Progress of the Steam Engine, with an Extensive Appendix by Luke Herbert*, London, 1831, pp. 849-56.

may have weakened the French technological/innovation system and have allowed the tendency towards handicraft, commercial, imperial and foreign developments to continue to hold sway over manufacturing industries for a longer period.

Finally, we might note the continued importance of artisan workshop production in the successful industrialisers – for France, Markovitch calculated that in 1876 artisan employment was twice that of factory (or large scale industrial) employment. We might also emphasise that artisan training and technique continued to be of huge importance in all major industrial nations – indeed, in the much-vaunted German case, modern factory industries seemed to gain a great deal by drawing off skilled artisan labour from the smaller firms, this possibly being every bit as important as the more over-emphasised processes of training associated with new schools, polytechnics and universities.[93]

7. Conclusion: Exceptionalisms.

Notionally, there are several paths by which historical exceptionality might come about. System X may uniquely possess magic ingredient B. Or system X may possess magic ingredient B beyond a certain threshold, below which it does not yield significant material effects, when no other system has achieved this. Or it may be that system X holds magic ingredient B within a conjuncture of other, quite diverse elements that together, and uniquely so, provide the necessary and sufficient conditions

[93] T.J. Markovitch, 'Le revenu industrielle et artisanal sous la Monarchie de Julliet et le Second Empire', *Economies et Societes*, ser. AF 8 (1967); J. Kocka, 'Craft Traditions and the labour movement in 19th Century Germany' P. Thane et al eds., *The Power of the Past: Essays for Eric Hobsbawm,* Cambridge, 1984, pp.95-117; J.J. Lee, 'Labor in German Industrialisation' in P. Mathias and M.M. Postan, eds., *The Industrial Economies, The Cambridge Economic History of Europe,* VII pt. I, Cambridge University Press, 1978, pp. 442-497. 50% of all German apprentices were trained in firms of 6 workers or less, another 20% in firms employing 6-20 workers – so large state-contracting industrial enterprises were free-riding upon artisan workshop production.

of a leap into material progress. Or there may exist no magic ingredient B, and system X may yet possess a unique conjuncture of elements [any or all of which might have filtered into system X from a universe of other systems] which together [but only together] act as a necessary and sufficient condition for a leap into material progress. Or it may be, as in some version of the Crafts conjecture[94], that more than one system sat at any of these possibilities, but that only one race was ever run and thus only one victor ever emerged to be analysed as such by its later historians.

There seems to be a case for the absence of an ingredient B in global history, and for the identification of combinations of the last two notional cases as the major characteristics of the great watersheds. For a while the first leap monopolises things and cuts out contemporaneous replication, in a manner similar to the curtailment of Mertonian multiples in intellectual history.[95] We increasingly accept that the work of economic historians now shows that in basic conventional measures of labour productivity and real standards of living, Europe was not exceptional even by the later 18th century. Nevertheless, we have argued here that in some other terms Europe seems to have been exceptional by and during the 18th century. In terms of the intellectual and cognitive elements in material production, such exceptionalism was not primarily at the level of a unique creativity, though even here there is clearly room for much debate. Less doubt attaches to the more mundane but powerful argument concerning the social and spatial locations and applications of URK.[96]

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[94] N. Crafts, 'Industrial Revolution in Britain and France', *Economic History Review*, 30, 1977, pp. 429-41.

[95] Very well-known of course but see R.K. Merton, 'Singletons and Multiples in Scientific Discovery', *Proceedings of the American Philosophical Society*, 105, 1961, pp. 370-86, and D. Lamb and S.M. Easton, *Multiple Discovery,* London, 1984.

[96] It is never to late to warn others by invoking the Gerschenkronian insistence on the distinction between exceptionality of *performance* (which Europe may have had little of in the 18th century) and exceptionality of *potential* for proximate future growth as a result of accumulations of measurable and varied assets, (which Europe had

We might quite happily accept that such characteristics of European URK evolved during the 18th century from somewhat earlier assets, which were formed and acted as cultural and institutional exceptionalisms, as summarised in sections 2 and 3 above. But there was no necessary transmogrification from the great advancements in the natural sciences to the evolution of British-style URK in the later 18th century. Much of Europe shared the scientific revolution but – as we have suggested - relatively few sites exhibited themselves as places of URK quite as strongly as they did in Britain. And it is just as important to restate that such transformations took time, depended on a host of institutional, demographic and spatial variables, and could not easily be emulated by other systems or transferred elsewhere.[97] This

something of). Because economies are complex things embedded in far more complex socio-cultures, discontinuities in material output may be absent contemporaneously with marked discontinuities in the forces that create output. See the nuances of P.A. Gerschenkron, *Continuity in History and other Essays*, Cambridge Mass., 1968; see also Ian Inkster, 'Politicising the Gerschenkron Schema: Technology Transfer, Late Development and the State in Historical Perspective', *Journal of European Economic History*, 31, 2002, pp. 45-87.

[97] This part of the argument is allowable just because from the 17th century 'Britain enjoyed somewhat more widespread and sustained patterns and rates of Smithian growth and thus moved more rapidly than other regions of Europe (and East Asia) up to that plateau from where technological progress and an Industrial Revolution became potentially likely (and with hindsight) all too probable' So it seems that for some historians, features of Smithian growth provide the assets for post-Smithian technological change. In this quotation Patrick O'Brien sets up his own scepticism of the long-run perspective, arguing that the industrial revolution was a profound conjuncture in its own right. Here we agree, but think that this was so precisely because in Britain a clutch of long-term features met in conjuncture with a range of newer, 18th century features to forge a specific outcome. In this conjuncture, we would argue that amongst the most outstanding of new features was the character and the numbers of the sites of URK in Britain, but especially in England and Scotland. So the British case is not so much an inevitable and gradual culmination as a specific discontinuity brought about by the triggering effect of shorter-term, institutional forces, upon the workings of more Smithian long-term processes. This demands no recourse to a theory of deep cultural or mental exceptionality in Britain, nor does it require a sudden spurt of industrial growth, which seems to come more with the emergence of machinofacture in the 1830s. Cf. see Patrick K. O'Brien, 'The Reconstruction, Rehabilitation and Reconfiguration of the British Industrial Revolution as a Conjuncture in Global History', *Itinerario*, 24, 2000, pp. 117-34, quote p. 126. Again, the precautions and subtleties suggested by Gerschenkron (above) are worthy of remembrance else we re-invent the wheel yet one more time.

generalisation is almost certainly applicable to the years prior to the 1830s, but is even more salient for the machinofacture period after that time.

Within Europe, England and Scotland appear to have possessed a unique combination of socio-institutional assets.[98] This may best be finally summarised in terms of a return to the well-trodden contrasts between Britain and France.[99] In both nations the natural and experimental philosophies flourished, and in both they were located well beyond the gentlemanly conversations and disputations of the academies and universities. But the second half of the 18th century did seem to witness a real distinction between the two nations in terms of the social and spatial location of URK more specifically. Mokyr has summarised the distinction in characterising the British URK enterprise as spontaneous and generated by private interests, in contrast to France where 'scientists depended on economic and personal relations with the political establishment, fostering an elitist and statist approach to science, which was thus particularly concerned with the engineering and technical needs of the state and above all with military needs'.[100]

Firstly, Britain became far more of both a recipient and a transmitter of URK and of techniques within the wider Western setting, and this

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[98] In this already lengthy paper we have not had an opportunity to show the URK-based differences and connectivities between England and Scotland, but for brevity see Inkster op. cit (1991), pp.73-8 and passim (forthcoming) 'Urban Association, Reliable Knowledge and the Sources of Technological Progress – the Case of England circa 1780-1914'.

[99] See however, Patrick O'Brien, 'Path Dependency, or Why Britain became an Industrialised and Urbanised Economy long before France', *Economic History Review*, 49 (1996), pp. 213-249. for novelty in institutional; comparison see Liliane Perez, *L'invention technique au siecle des Lumieres,* Albin Michel, Paris, 2000.

[100] Joel Mokyr, 'The New Economic History and the Industrial Revolution' in Mokyr ed., *The British Industrial Revolution. An Economic Perspective*, Westview, Boulder, 1993, pp. 1-131, one of the most refreshing of surveys in existence to date, quote p. 81. I would, as here, emphasise as much the contrasts between the two nations in the social and geographical siting of URK, as much as in the differential attachments of science to either state or commercial elites, but the point is central to that approach and remains a good one. See below.

appears to have been a direct outcome of the broadening base of the English and Scottish urban intellectual culture described above.[101] Secondly, in France the 1789 revolution and the subsequent revolutionary wars created a contrasting social location for the natural sciences and, thus, for their status as URK. Gillispie has shown that during the later 18th century the links between French science and French industry had become increasingly mediated by the needs of the French state.[102] Science was highly civic and elitist, gaining support primarily through increasingly professional, service contracts with the state. After 1789 the sciences became even more politicised in this manner. In the first years the disestablishment of French science was illustrated in the closing of the scientific work of the Bureau de Commerce in 1791 and the entire closure of the Academie. At a later stage French science was somewhat reimbursed (despite the disappearance of such key figures as A.L. Lavoisier (1743-1794) and the Marquis de Condorcet (1743-1794)) with the foundation by the state of the Lycee des Arts and the Societe d'Histoire Naturelle. A patent system was established that provided 15-year protection, there was reform in technical education and state activity in the collection and exhibition of machinery. In a third phase, French science was re-established under the state. Remnants of the ancient regime survived in Sadi Carnot (1796-1832), de Morveau and Fourcroy, but under official auspices were newly founded the mining colleges (1793) and the Polytechnique (1794), and much of the work of the Academie was now turned over to the Institut de France, and both of these elite sites were directed to serve imperial and military functions.

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[101] For something of a model linking internal institutions with patterns of knowledge and technique transfer see Ian Inkster, 'Mental Capital: Transfers of Knowledge and Technique in Eighteenth-Century Europe', *Journal of European Economic History*, 19, 1990, pp. 403-41, which follows a generally Humean approach.

[102] C.C. Gillispie, *Science and Polity in France at the End of the Old Regime*, Princeton 1980. The commercial breakthrough of Nicholas Leblanc (1742-1806} in 1789-90 originated in the ancient regime task of making sal ammoniac from urine and salt, and was applied as a best technique in Britain rather than France.

The Ecole Polytechnique absorbed much French talent into research programmes in mathematics, chemical nomenclature, the thermodynamics of the steam engine, the theory of light, electricity and the turbine. Military needs supported highly professional work on hydrogen production for ballooning, the manufacture of saltpetre, and soda and chemical manufacture by chemists.[103]

Whether science benefited in France from such institutional machinations is not our concern here. Our claim would be that French sciences survived revolution and wars by becoming less rather than more URK. The creativity of J-L. Gay-Lussac (1778-1850) or A.J. Fresnel (1788-1827) was to evolve alongside a statist search for such strategic products as salt and sugar and an increased bureaucratic and imperial national scientific enterprise. In striking contrast with Britain, the payment and politicisation of French scientists created a modern elite, an instant scientocracy, where merit was rewarded without recourse to the dissemination and application activities so strongly associated with the sites of URK across the Channel. The audience for French science was the French state. So, throughout most of the 19th century, French science could remain both creative and professional as well as elitist and independent of the demands of the growing industrial classes for URK and improved technique.[104]

In France we might hazard the generalisation that decentralised provincialism had to struggle for its existence and tended to be stripped of much potential talent and resources by the continuing tendency towards Parisian and statist centrality. This created an interregnum that was only really broached in the strong movements of the 1870s and 1880s centred on the several hundreds of Societies Savants and their voluminous

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[103] C.C. Gillispie, *Lazare Carnot savant*, Princeton 1971; L.P. Williams, 'Science, Education and the French Revolution', *Isis*, 44, 1953.
[104] R. Fox, 'Scientific Enterprise and the Patronage of Research in France 1800-1870', *Minerva*, 2, 1973.

scientific and technical transactions and memoirs. Now the stress was certainly on localism, witness the provincial work of the Ecole pratique des hautes etudes.[105] In comparison to Britain, then, can we suggest a relative weakness in decentralised, urban and artisan-based associations for reliable knowledge and its applications in France, circa 1820s-1860s? We are not positing a fatal absence or a series of lacunae, merely a comparative weakness in terms of both quantities and qualities, and one that may help in understanding contrasting industrial trajectories.

It may be seen that such contrasts might serve to strengthen any arguments that insist on a distinction between URK and the national scientific enterprise and that turn attention away from elite forums and towards the socio-spatial character of innovative sites of technological endeavour, modification or emulation.

A novel perspective on Britain in a global context, which sufficiently distinguishes it from its closest commercial competitors within Europe, might now run as follows: the attainments of the industrial sector were already high relative to other parts of Europe by mid-18th century, and the subsequent 80 years of growth were relatively slow, with a renewed higher growth rate in the 1830s.[106] The slow period was associated with a flow of breakthrough technological innovations that did not yet have any remarkable impact on overall economic progress.[107] Although the case

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[105] See the debate between Ben-David and Clark in *Minerva* 8 (1970), 160-79, 599-601; H.W. Paul, 'The Issue of Decline in 19th Century French Science', *French Historical Studies,* 7 (1972); Robert Gilpin, *France in the Age of the Scientific State*, Princeton, 1968; and the extremely refreshing emphases on voluntarism and provincialism in Robert Fox, 'Learning, Politics and Polite Culture in Provincial France; the Societes Savants in the 19th Century', *Historical Reflections* 7 (1980) and his 'Science, Industry and the Social Order in Mulhouse 1798-1871', *Brit. Jrnl. Hist. of Science*, 17 (1984).

[106] This is a rough rendering, but hopefully a fair one, of the position developed in N.F.R. Crafts, *British Economic Growth,* Oxford, Clarendon Press, 1985, Crafts and T.C. Mills, 'The industrial revolution as a macroeconomic epoch: an alternative view', *Economic History Review*, 47, 1994, pp. 769-75.

[107] I do not think that this is to agree with Harley in 1993 when he wrote that the 'famous technical breakthroughs .. of the 'Industrial Revolution' were .. probably quite a

remains problematic, these decisive innovations may have owed something to the mechanical philosophies and URK generated during and after the so-called Scientific Revolution, allowing for the possibility that the seeming growth of industry prior to circa 1750 might have depended more on an URK located in work skills and associations. During the latter part of the slow-period Britain witnessed an unusual amount of institutional innovation across a range of socio-cultural sites and activities, but including ones that generated, honed, and multiplied URK in an increasing number of places amongst a greater social variety of peoples situated in a social system that was both open to the influences of other systems and similarly open in terms of increased degrees of socio-cultural mobility. The higher growth of the 1830-1870 years was associated with the development of machinofacture, which centred on both new technologies and new institutions and a great acceleration in the number of URK sites and audiences. The new post-circa 1830 technologies served to broaden the scope and reduce the usage costs of earlier technological changes, and thus tended to have a large impact on overall industrial efficiency and growth.[108] The new institutions especially included the reformed patent system, which not only broadened the social base of inventive activity and ushered in the age of general machine

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small part of the process of growth', for this can be taken to mean the impossibility of strong explanative links, where I take the relationship as I have tried to state clearly here, as one where technical changes were indeed preparing the British industrial system for the growth of later years. See C.K. Harley, 'Reassessing the Industrial Revolution' in J. Mokyr ed., *The British Industrial Revolution,* Boulder, Westview, 1993, pp. 171-226, quote p. 224. For the wider perspective see Mokyr Introduction in ibid, and Jan de Vries, 'Economic Growth before and after the Industrial Revolution', in M. Prak ed., Early Modern Capitalism. Economic and Social Change in Europe 1400-1800, Routledge, London, 2001, 177-94.

[108] We continue to agree with Rosenberg that inventions 'when they are first introduced or apatented, are typically very far from the form that they embody when they eventually achieve wiodespre4ad diffusion; or, to put it differently, it is the improvements that they undergo that finally lead to widespread diffusion'. Here we are arguing that the 1830s onwards witnessed a very large surge in incrementalism that served to cheapen, broaden and diffuse inventions created or brought to initial use at an earlier period. See D.C. Mowery and N. Rosenberg, *Paths of Innovation*, Cambridge University Press, Cambridge, 1998, quote p. 2.

engineering, but also induced a need for knowledge search and certitude, which in turn fastened the bulk of an increasing URK closer to the places of production and industrial innovation.[109] This process yielded a conjuncture of institutions and technologies that provided Britain with an industrial advantage for some time. Birmingham's could not be multiplied by rulers, interests or markets elsewhere. That is, the extreme direct and opportunity costs, the complex institutional and legal imperatives of this system rendered it difficult to emulate, much as was the so-called American System of Manufactures on the other side of the growing Atlantic material domination of the globe. Late developing systems in reasonable spatial and cultural proximity to this machinofacture system shared some of its characteristics and could substitute others with a range of new institutional innovations – from Polytechniques[110] to patent systems. Places beyond this particular pale – with the possible exception of Japan – faced much greater difficulties despite their costly attempts to emulate the same institutional and technological complex. The 20th century in its shorter version – 1914-1971 – demonstrated over and over again the extreme problems involved in catch-up under a regime of machinofacture. For East Asian catch-up and the emergence of a multiplicity of contending developing cores at the global level, machinofacture had to go.

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[109] Using patent data only and partial construction of US occupational material, Khan and Sokoloff have suggested that prior to 1850 the US patent system was effectively more broadly based in social terms than that of England and that this measured a difference in the character of technological change more broadly. This remains to be tested more historically and with due concern for differences between institutions, but it would be interesting to measure this contrast after 1851/2; see B.Z. Khan and K.L. Sokoloff, 'Patent Institutions, Industrial Organization and early Technological Change: Britain and the United States 1790-1850, in M. Berg and K. Bruland eds., *Technological Revolutions in Europe. Historical Perspectives,* Edward Elgar, Cheltenham, 1998, pp. 292-314.

[110] Most states that adopted patent systems in the 1840s had created technical universities and polytechnics before that time – so Prague 1806, Vienna 1815, Dresden 1828, Stuttgart 1829, Hanover 1831, Darmstadt 1836, Lausanne 1853, Zuirich 1855.