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# HISTORICAL PERSPECTIVES ON THE INTERNATIONAL TRANSFER OF SCIENCE AND TECHNOLOGY

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### *Introduction*

Science emerged as an integral component of modern culture as a result of the "scientific revolution" of the sixteenth and seventeenth centuries.[1] The new, revolutionary, mechanical and natural philosophy, and the new tradition of experiment and observation began in a few cities on the Italian peninsula, spread to urban centers in Western Europe, through colonial channels to the Americas, India, the Far East, and recently to the far corners of the world. With the sciences playing an increasingly important role in modern societies, historians of science are making the eminently reasonable claim that the scientific revolution and its long-term consequences must be seen as playing a central role in Western as well as World history -- equal to or more than even the Renaissance, Reformation, Enlightenment, or the rise and fall of particular empires.

However impressive, the modern scientific revolution was itself based on the foundation of earlier innovative technologies such as the mechanical clock and the printing press, and new industrial activities such as mining, metallurgy, and ship building. In return, science contributed to the spread of industrial civilization from the British Isles and the New England region in the eighteenth and early nineteenth centuries, and to all the nations of the world in the mid- to late-twentieth century.

This paper provides an overview of and a structure for studying the transfer of science and technology from one nation or region to another over a period of three centuries, from the 1650s to about 1945. Obviously, this is an immense topic to consider for even a *single* nation and could provide the basis for a series of conferences or for a multi-volume work. One paper can do little more than establish the basic themes and concerns that would be embraced in detail in a longer study. Therefore, while I will sketch the broad outlines of the rise and transfer of science and technology within and between nations, a detailed analysis of the spread and influence of specific theories and inventions, and the role of individual nations and locales must await a longer, more comprehensive treatment. The historical approach taken in this paper, however, should be valuable for placing the overall discussions of this committee on *interdisciplinary approaches to development and modernization,* into a larger context.

While the focus of discussion remains on contemporary problems and future trends in development and modernization (and rightly so), a historical perspective provides opportunities to search for common factors in the international transfer of science and technology. Historical perspectives may provide illumination helpful in penetrating the "fog" of technology's social dimension. These perspectives may also, I should warn, confuse the issue, although not perniciously so, by illustrating the complexity of social interactions and the critical role of individuals, details, concepts, and contexts in the development and diffusion of science and technology. Historical agreement is perhaps as elusive as agreement on current issues. This is not to deny the possibility of a "New Cultural Revolution," but to state that historical wisdom (and other types of wisdom) is needed to temper simple enthusiasm.

### *Science and Religions*

While the Protestant Reformation was both coterminous and coincidental with many of the foundations of the technological and scientific revolution, it was the new exegesis of the book of nature, rather than new interpretations of the books of Christian scripture, which caught the attention of the modern world. In general, science and technology are not only more widespread than any individual religious tradition, they are also more catholic and more ecumenical. By this I mean to say that the two major social forces represented by religion and science are quite different in nature and activity. While there are innumerable religious sects and associated worldviews, each closely related to a particular cultural and symbolic system, scientific orthodoxy maintains that nature and nature's laws are universal and largely independent of social and cultural settings. For good or ill, science and technology have become pervasive agents of change over the past five centuries (see Table 1).

Table 1: Comparison of the claims made for two general historical forces, Religions and Science

| *Religions* | *Science* |
|---|---|
| Numerous worldviews | Unified worldview |
| Various symbolic systems | General symbolic agreement based on method & mathematics |
| Socially & culturally determined | Socially & culturally shaped |
| Bounded only by imagination (i.e. unbounded) | Bounded by nature and available technology |
| Ancient heritage primary (historical focus) | Ancient heritage secondary (ahistorical focus) |
| Ancient wisdom tradition | Greek philosophy |
| Revelation | Reason |
| Ecumenism the exception | Ecumenism the rule |
| Change = retrenchment | Change = progress |

### *International and national dimensions*

While most historians of science tend to emphasize the international nature of "the republic of science," much of the rest of history is written in a national, even nationalistic, framework. While it is difficult to argue with Newton's dictum that: "the descent of stones in Europe and America must both be explained by one set of physical laws," or Chekov's dictum: that there is no national science just as there is no national multiplication table...," yet the social environment and training of scientists cannot be ignored.[2] Undoubtedly, the local social setting helps mold the conceptual growth of science and technology by preferentially selecting certain problems, approaches, and schools of thought as the most worthy. It also influences the numbers and types of individuals who join the scientific ranks. In its most extreme form, this position maintains that scientific knowledge is "socially constructed" with little or no constraints being imposed by nature. One of the dangers inherent in this view of knowledge is repeating the type of fallacy committed by Nazi theorists, who maintained that science is a direct reflection of racial or national spirit.[3]

Few scholars have explored the connections between the rise of modern science as a major force in history and the rise (and decline) of individual modern scientific nations. The cognoscenti (predominantly Europhiles) have been primarily those who make the sweeping claim that science is essentially international: there is no national science, while conceding only that there are scientists who hail from particular nations. Even among historians of American science, for example, the majority hold the position that the "exciting" period came only late in the nineteenth century after patterns which were comparable to those in European science began to emerge. The earlier, pre-colonial, colonial, and early national periods are often dismissed out of hand as lacking in interest or importance.

Some scholars go so far as to try to impose twentieth-century expectations and organizational models on the history of these earlier, "pre-disciplinary," and pre-professional eras. The noteworthy literature is usually narrowly focused on biography or individual case studies. What is clearly needed is a synthetic investigation of the foundations of modern science which covers a broad range of individuals, institutions, and scientific specialties; which explains the processes of scientific and technological transfer and diffusion; and which focuses on the international flow of ideas about nature and inventive techniques and technologies, while delineating their context, circumstances and broader social and cultural implications.

Fortunately, an influential article by George Basalla set the agenda for historical work on the topic of scientific transfer.

Historians of science have often attempted to explain why modern science first emerged within the narrow boundaries of Western Europe, but few have considered the question posed by Basalla:

> "How did modern science diffuse from Western Europe and find its place in the rest of the world?"[4]

A similar question must be asked in the case of technology.

### *Mechanisms of Transfer*

One obvious mechanism for the transfer of science and technology is through direct contact between a less developed country (LDC) and a more developed country (MDC). This may occur on a grand scale through exploration, military conquest, colonization, imperial influence, commercial and political relations, missionary activity, etc. Direct contact also occurs on the individual level through travel and study abroad, and through intellectual migration. Thus the Spanish explorers and conquistadors of the 15th and 16th centuries, the British traders and colonists of the 17th and 18th centuries, American professors and students abroad in the 19th century, the muses fleeing Hitler in the 20th century, international students completing their training in the United States and the Soviet Union, and multinational corporations doing business with nations of the the third world, all have at least one thing in common: they all represent vectors of scientific and technological transfer between MDCs and LDCs.[5] One author found the steamboats on the River Ganges in the 1830s to be, "vectors of Western Civilization carrying Western science, medicine, and technical skills into the interior of India."[6]

While there are numerous case studies of international transfer of technology that treat recent developments, there are as yet few studies that have taken up the challenge for an extended period of history. There are also few studies treating the spread of science A notable exception is a new book edited by Nathan Reingold and Marc Rothenberg entitled *Scientific Colonialism: A Cross-cultural Comparison.*[7] In general there are two basic cases: interaction with ancient "complex" cultures, and with "indigenous" cultures (typically leading to their extinction). Most of the case studies compiled by Reingold and Rothenberg treat the latter case using America and Australia as examples. A more wide ranging article by Macleod in the same volume enumerates and describes the following stages characteristic of the spread and conduct of science in the British Empire: (1) Metropolitan (2) Colonial (3) Federation (4) "Efficient" Imperialism (5) Empire and Commonwealth.[8] In general it is true that the development of science and technology and its international transfer follows national fortunes: from Britain to the colonies in the 17th century; from France to Russia in the 18th; from Germany to its colonies in the 19th; and from the U.S. to the world (and now from Japan to the U.S.) in the 20th century.

Moreover, there is no reason to limit our conceptual umbrella to the modern period, especially when the focus is on technology or "techne." Were not the arts and craft foundations of the Roman Empire derived from the ability of the Romans to conquer and assimilate the accomplishments of other cultures, particularly that of the Greeks? And were not the technical foundations of medieval Europe on the eve of scientific awakening transmitted through Islamic vectors from more ancient civilizations? Moreover, the chroniclers of modern Western civilization need not be too proud, for now the European nations which founded the sci-tech tradition are in relative retreat compared to their proteges. Even the star pupil, the United States, is being eclipsed by recent developments in the Orient. In general, all MDCs were once LDCs; and in fact, role reversals may not be at all uncommon when considered over long periods of time.

### *A taxonomy of the stages of sci-tech transfer*

With such diverse activities and time periods being represented by the concept, *science and technology transfer*, it is appropriate to provide a taxonomic structure to this diverse yet somehow unified and universal activity Because the details of each episode are of crucial importance -- i.e. the individuals involved, the fields and specialties represented, the rise and fall of sci-tech fortunes in both the MDCs and LDCs, etc., this taxonomy will serve as an overall guide to those investigating particular cases.

*Taxonomy:*

*I. Exploration phase*: the natural phenomena and native populations of a LDC become the subject of scientific research by individuals from a MDC. Topics usually involve, geographical, geophysical, or ethnographical problems. There is no scientific infrastructure in the LDC. Research results are reported to the scientific societies of the MDC where they are published. Researchers return to the MDC at the completion of their studies taking their scientific equipment and results with them.[9]

*II. Colonial phase*: Scientific activity by citizens of the LDC is dependent on the institutions and traditions of the imperial cultural center of one or more MDCs. This center need not be the political center of empire. The older and more prestigious scientific societies and universities of the MDC provide credentials for colonial scientists as well as places for them to study. The choice of scientific research topics is usually determined by scientists in the MDCs, while colonial scientists pursue supplementary research. There is, as yet, little industrial capacity in the LDC, and no capacity to produce scientific instruments. Equipment is procured from the MDCs for research and for training students at colonial schools.[10]

*III. Emergent phase*: This phase, often fueled by nationalist sentiment, involves the struggle by citizens of the LDC to establish an autonomous, domestic scientific and technological infrastructure and tradition.[11] According to Basalla, this emergence faces the following obstacles:

1. Native scientific organizations must be founded.
2. Formal channels of communication, both nationally and internationally, must be established. This includes incentives for LDC scientists to publish their results LDC journals which may be less prestigious than MDC journals. The question of the use of native languages must be addressed, particularly outside the West.
3. A proper technological base, including urban and industrial support, must develop with the capacity to produce instruments for research and teaching.
4. The teaching of science must reach all grade levels.
5. The LDC government should be supportive or at least neutral on scientific and technological policy matters. They could well learn from the Japanese government which does everything possible to promote science for national development.
6. Resistance to science and technology from native religious beliefs and customs, and philosophical traditions must be addressed. Adverse technological impacts must be minimized.
7. The social roles of scientists and engineers must be raised to a level of approbation to encourage recruitment and retention.

Any one of these seven tasks represents a major problem. Collectively they represent a severe challenge to even the most sincere and concerted efforts of scientists in the LDCs. Here Basalla's three-stage model ends. Levels four and five, however, must be added to his model for completeness.

*IV. Scientific and Technological Maturity (?):* This phase follows from the attainment of the seven imperatives listed above. However, it is not a forgone conclusion that any nation will succeed in reaching maturity in this sense (thus the question mark above). The leading nation or nations at the pinnacle of attainment in any given epoch -- such as Italy (ca. 1620), Britain (ca. 1750), France (ca. 1830), and Germany (ca. 1880) -- represent *world leadership* in science and technology. Such hegemony was maintained by the nations of Western Europe from the 17th century to about 1930. Since 1930, the United States -- initially in the fields of genetics and astrophysics, and subsequently in physics, computer technology, and most other specialties -- emerged as the leading scientific nation. The Soviets, with a distinct bias toward the applied sciences and relatively few Nobel Prize winners, have established leadership in weaponry and space technology since the 1950s. It has taken the United States and the Soviet Union several centuries to reach and surpass the scientific and technological accomplishments of the nations of Western Europe. Now Japan is making a bid for the first position. Australia and Canada, although fully industrialized, form a rather permanent second rank because of their small size. China and India have enormous untapped potential, yet face severe domestic problems largely linked to their large populations and to widespread poverty. A spectacular success story, however, comes from the nation of South Korea. This nation suffered domination by its more aggressive neighbors throughout its history. Although the forty year period of Japanese colonization from 1905 to 1945 was a national tragedy for the Koreans, the Japanese left it with a highly developed system of roads and good schools as well. South Korea reached technological maturity in the four decades following World War II.

*V. Eclipse and Decline Phase* (?): A nation reaching the stage of scientific and/or technological maturity may or may not maintain its hard-won gains. This is certainly true for numerous ancient civilizations which had highly developed technologies, yet lost their role as world leaders and their sovereignty as well. In modern times, the nations of Western Europe are in relative decline compared to their historical "golden eras." Even the United States is now facing hard questions relating to the distribution of scarce resources for scientific research. Hard choices are also necessary due to the increasing urgency and cost of repairing and maintaining its aging, low-tech, public works, such as bridges and highways.

*VI. Re-Emergence* (?): This is a rather hypothetical stage of development, although it could be argued that Soviet science, for example, re-emerged after World War II from a brief period of eclipse under the regime of Joseph Stalin. The war-shattered infrastructures of Japan and Germany have also be rebuilt. This re-tooling contributed to the major roles these nations now play in technological innovation.

### *Focus on Technology Transfer*

In the growing literature on technological transfer, technology is increasingly defined in reference to its economic and social context. While most scholars still consider only the transfer and diffusion of technological *artifacts*, some are beginning to recognize that the study of artifacts must be combined with the study of the international transfer of labor and managerial skills (*human resources*). As one historian noted, "It seems fairly clear that... the diffusion of technology was chiefly effected by persuading skilled workers to emigrate to regions where their skills were not yet plentiful." [12] Indeed, the often neglected human dimension is now seen as the major constraint in technology transfer to less developed countries. This expanded viewpoint involves the following levels of technology transfer:

1. machines or artifacts;
2. operative capability -- the ability to operate, run & maintain the machines;
3. investment capability -- the ability to develop new productive capacity;
4. innovation capability -- the ability to modify and improve products and processes implying a stable level of transfer.[13]

The *timing* of the transfer is also important. Sanders has shown that the development of a new principal technology typically follows an S-shaped growth curve [14] During the period of "tight control," the technology is developed, patented, and marketed in the more developed nations. As second generation spin-offs begin to emerge and the first generation reaches its limits of performance and marketability, economic imperatives sweeten the prospects for "transfer" of the first generation of machines (e.g. computers), to less developed nations. Proprietary controls are loosened on the older generation and the cycle begins again for the second generation. Thus, in most cases, LDCs represent a secondary market in a world economy dominated by the MDCs and they receive equipment and technologies which are nearing economic eclipse or obsolescence.

and the United States proceeded over many decades. Although the social adjustments were both dramatic and at time severe, the process was a gradual one tempered by an ongoing social debate, the rise of labor unions, new forms of management, and new government laws and initiatives. One study of the diffusion of new technologies in six West European countries suggested that "countries which are pioneers [of a particular technology] tend to have *slower* speeds of diffusion, partly due to "teething problems" which are partially or gradually solved by the time that others adopt it."[15]

Of course the technical problems may be solved, while the social problems are either ignored or denied. The increased speed of introduction of a new technological product or process developed in one country (typically a MDC), into another society (typically a LDC), may in fact be strongly related to the impact of the cultural shock. I would go even further and define *technological momentum* (a measure of ability to administer a cultural shock) as the product of technological novelty and the speed of its introduction into a society. Moreover, the total *technological impact* will depend on the technological momentum and the society's ability to absorb the shock (a measure of the mass of the native technological infrastructure and the prevailing religious and philosophical value systems in the society). The implication here is that societies with undeveloped infrastructures and traditional value systems will experience the greatest social *displacements*, everything else being equal. Obviously, the most likely points of entry of transferred technology will be in the cities of LDCs. This may serve to increase the difference between urban and rural society within a nation and increase the tensions between two competing lifestyles and systems of values.

There is also the possibility that the LDC is merely imitating the practice of the MDC without consideration of the appropriateness of the technology or its overall balance with the rest of society. A study presented by Harvey F. Ludwig at ICUS XV in 1986 focused on the problems of the education of students of LDCs at educational institutions in MDCs. For example, a civil engineering student from Thailand studying at MIT or Cal Tech will typically learn the engineering standards of the MDC. Then, with little or no apprenticeship, the LDC student will return to their native land (if they return at all), typically serve on a government commission, and eventually be appointed to a blue ribbon panel or cabinet level position in the LDC. In the process, the MDC trained engineer will have done little or no actual engineering projects in the LDC in his or her career. In fact, persons with elevated credentials may in fact be unable to complete practical engineering projects, since they studied the principles and practices of engineering in the MDC (which are inappropriate for the LDC) and served an inadequate apprenticeship.[16]

### *Conclusion*

The advantages of taking a historical approach to the problem of the international transfer of science and technology should be apparent by now, if only in pointing out the dangers inherent in focusing too narrowly on current experience. Science has been an important aspect of modern experience for at least three centuries; technology for several millennia. Moreover, the scientific community is committed to a unified worldview based on nature and human reason. This is not to say that important differences do not exist between nations. Indeed, national differences, styles, and social influences lie at the heart of the study of mechanisms and stages of scientific and technological maturity and transfer.

Much of the current literature, especially on technology transfer alone, is beginning to include more of the human dimensions, over and above the simple transfer of machines and processes. However, the "socio-technical" dimension of values and cultural impacts remains largely ignored. While historical analysis provides guidance and valuable insights by looking at the broad outlines of developments spanning several centuries, it makes no claims to authoritative judgements, or special wisdom. Yet it serves to remind us of the complexity of human experience as it sets the stage for detailed case studies of particular incidents and episodes.

## ENDNOTES

[1]It was Herbert Butterfield who endowed the phrase, "scientific revolution" with its modern meaning. See Butterfied, *The Origins of Modern Science* (1957, revised ed. New York: Free Press, 1965), p.7; and Henry Guerlac, "Science and the Historian," in *Essays and Papers in the History of Modern Science*. (Baltimore and London: Johns Hopkins Univ. Press, 1977), p.43.

[2]Isaac Newton, *Principia*; Anton Chekov, *The Personal Papers of Anton Chekov* (New York: Lear, 1948).

[3]R.K. Merton in *The Sociology of Science*, B. Barber and W. Hirsch, Eds. (Glencoe, IL: Free Press, 1962), pp.19-22.

[4]George Basalla, "The Spread of Western Science," *Science*, n.s. 156 (5 May 1967): pp.611-22; quote from p.611.

[5]See Rashwan Mahfouz, "Technological Transfer and the Growth of the Multinational Corporation," (Ph.D. dissertation, Univ. of Freiburg, Switzerland, 1975), especially pp.76-86.

[6]H.T. Bernstein, *Steamboats on the Ganges* (Calcutta: Orient Longmans, 1960).

[7]N. Reingold and M. Rothenberg, eds. *Scientific Colonialism: A Cross Cultural Comparison* (Washington, D.C.: Smithsonian Institution Press, 1987).

[8]Roy Macleod, "On Visiting the 'Moving Metropolis': Reflections on the Architecture of Imperial Science," in Reingold and Rothenberg, *op.cit.*, 217-49.

[9]See I.B. Cohen, "The New World as a Source of Science for Europe," *IX Congreso Internacional de Historia de las Ciencias* 1 *Textos de las Ponencias* (Barcelona & Madrid: 1959): pp.65-93.

[10]See for example, Raymond Phineas Stearns, *Science in the British Colonies of North America* (Urbana: Univ. of Illinois Press, 1970).

[11]A case study of this phase for the United States is Robert V. Bruce, *The Launching of Modern American Science, 1846-1876* (New York: Alfred A. Knopf, 1987).

[12]A.R. Hall, "Early Modern Technology, to 1600," in Technology *in Western Civilization*, ed. Melvin Krantzberg and Carroll W. Pursell, Jr. (NY, 1967), p.1.

[13]See Charles T. Stewart, Jr. and Yasumitsu Nihei, *Technology Transfer and Human Factors* (Lexington, MA and Toronto: D.C. Heath, 1987), pp.1-4. On the adequacy and effectiveness of the channels for the spread of technology, see A.G. Kenwood and A.L.

Lougheed, *Technological Diffusion and Industrialization Before 1914* (New York: St. Martin's Press, 1982), pp.12ff.

[14]Ralph Sanders, "Penetrating the Fog of Technology's Social Dimensions," Technology in Society 9 (1987): pp.163-80, diagram adapted from figure 10 on p.178.

[15]G.F. Ray, "The Diffusion of New Technology: A Study of Ten Processes in Nine Industries," *National Institute Economic Review* (May 1969): pp.82ff.

[16]Harvey Ludwig, "Affluence Versus Effluents -- Marine Water Pollution Control in the USA and in the Developing Countries," unpublished paper presented at ICUS-XV (Washington, D.C., 1986).