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TECHNOLOGY TRANSFER: HISTORICAL AND CROSS-CULTURAL PERSPECTIVES

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ABSTRACT

All the technologies that are having an impact on our lives were developed and produced somewhere else, either in another country, in another state or region, or in a military or industrial research facility. The technologies were transferred to us, mainly as end users or consumers. For good or ill, they have transformed the way we live, work, play, and die.

This paper examines the human dimensions of technology transfer, especially the historical and cross-cultural dimensions. A study of history shows that the cultural equilibria of earlier eras have been disrupted by technological innovations. The eotechnic era gave way to paleotechnics and neotechnics. Now, we hope, an ecotechnic era is dawning.

Superimposed on this macrohistory of cultures, is the macrohistorical development of each nation and region of the world. As nations pass through formation, growth, and completion of their scientific and technological infrastructures, some have not yet matured (and may never do so); others have passed their zenith and have entered a phase of decline.

The cultural shock administered by the transfer of technology across cultural boundaries depends on the rate of introduction of a new technological product from one country to another and the technological mass of a society. Societies with undeveloped infrastructures and traditional value systems will experience the greatest social displacements, everything else being equal.

The salients provided by unequal rates of technological development in world cultural history and the histories of particular nations, combined with unprecedented rates of change of technologies, and the dawning of an era of global interaction, promises either a new world civilization or unprecedented social, cultural conflict and ecological disruption.

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Introduction

We live in a shrinking global village that has become so largely because of new technologies. Electric lighting, refrigeration, telephones, automobiles, airplanes, radio, television, nuclear weapons, guided missiles, CAT scans, and personal computers, to name but a few, all have had a tremendous impact on our lives, on society and its institutions, and on both particular cultures and our emerging sense of world culture.

All the technologies that are making such a difference were developed and produced somewhere else, either in another country, in another state or region, or in a military or industrial research facility. The technologies were transferred to us, mainly as end users or consumers. For good or ill, they have transformed the way we live, work, play, and die.

The literature on technology transfer is immense. Yet much of it consists of narrowly focussed case studies with little or no concern for history.[1] While we know much about particular technologies, and the mechanisms of technology transfer within a dominant culture, larger trends are often lost in the details. Moreover, the transfer of hardware often gets more attention that the social and cultural impacts. What is clearly needed is a synthetic study of the history, mechanisms, and processes of technology transfer which focuses on the international exchange of innovative techniques, ideas, and technological systems, while delineating their context, circumstances and broader social and cultural implications. In addition to a macro-historical look at technology transfer, such a study should examine the dynamics of technology transfer from more developed countries (MDCs) and its impact on less developed countries (LDCs).

Macro-history I: Trends in World Culture

Before the modern era, that is before the scientific and industrial revolutions, most of the technologies people used were built and used locally; people lived close to the land; change came very slowly, if at all. To use the language of Lewis Mumford, it was the "Eotechnic" era from Eos meaning the dawn.[2] Energy sources included water, wind, and muscle power; most things were made out of wood, stone, leather, and cloth. The highest embodiment of eotechnic craft is found in the clipper ship and the violin.

The industrial revolution inaugurated the "Paleotechnic" era of steam power in which the wealth of nations was based on mineral extraction, especially coal, iron ore, and precious metals. Imperial powers ruled colonial empires. Change came suddenly and irreversibly, often in the form of invading armies, or armies of invading settlers. The embodiment of paleotechnics is the locomotive and its train of cars, belching industrial pollution from its coal-burning steam engine, travelling on mass produced steel rails, carrying Europeans and their civilization into the frontier to conquer the land.

More recent revolutions, especially in chemistry and physics, have brought us what Mumford called, somewhat hopefully, the "Neotechnic" era, run on electricity and oil, generating lighter materials such as aluminum and plastics, and embodied in such creations as the modern automobile and airplane. Unfortunately, the abundance of materials has led to our "disposable" society and the problems of disposing of ever more and ever more toxic wastes. Dioxin, PCBs, Plutonium, and Pampers, were not part of the garbage of earlier societies. For most of us the neotechnic era is also one of overdependence on foreign oil, causing all sorts of problems for the world.

Going one step beyond Mumford, in 1991 I proposed that we need a new "Ecotechic" era which preserves the ecological health of the planet while recognizing the positive contributions of high technology.[3] The main features of such a global society would be a new era of international cooperation and a reduction of our obsession with accumulation, competitive performance, and power. Our machines would run on renewable energy sources, mainly sunlight, wind, water, and biomass; our factory products would be recyclable; any further growth would have to be sustainable; our ethic would be "less is more."

Macro-history II: Formation, Growth, and Completion

Science emerged as a central component of western culture after the "scientific revolution" of the sixteenth and seventeenth centuries.[4] The new 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. After 350 years, the scientific revolution must be seen as playing a central role in Western as well as World history -- equal to or more important than even the Renaissance, Reformation, Enlightenment, or the rise and fall of particular empires. Standing behind the scientific revolution were foundational technologies such as the mechanical clock and the printing press, and new industrial activities such as mining, metallurgy, and ship building. The spread of western culture, which may be traced in large part by the international diffusion of science and technology, reached all the nations of the world by the mid- to late-twentieth century.

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

> How did modern science diffuse from Western Europe and find its place in the rest of the world?[5]

To answer this question, Basalla posited a series of growth stages which nations pass through on their way to scientific maturity. Basalla was severely criticized for being a determinist and for oversimplifying the historical record. Moreover, he did not consider what might happen to a nation after it reaches scientific maturity, nor did he deal with technology.

While these criticisms are justified, still Basalla's taxonomy applies to most of the nations of the Western world, particularly the United States. With the addition of several later stages of development and the caveat that all of this is by no means inevitable or predetermined, the model serves a useful heuristic purpose.

Basalla's revised taxonomy is presented below:[6]

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.[7]

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.[8]

A mature scientific and technological infrastructure does not guarantee automatic "progress" or fairness. Before the United States had a patent system, Benjamin Franklin made the following remarks on mechanical invention as a communal possession:

> That as we enjoy great Advantages from the Inventions of others, we should be glad of an Opportunity to serve others by any Invention of ours, and this we should do freely and generously.

In other words, the modern patent system, although it promotes and rewards innovation, is not without its social costs:

> Inventing a new stove, like performing a scientific experiment, or organizing a Philosophical society, was in [Franklin's] view a contribution to collective well-being, and whatever benefits might issue from such acts of civic virtue should be considered public, not private, property.[9]

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.[10] This includes instituting a restrictive patent policy. According to Basalla, a nation in this stage 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 in stage III. 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, constitute 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. <u>Eclipse and Decline</u> (?): 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.

Such macro-historical perspectives, for world culture in general and for nations in particular, provide opportunities to search for common factors and recurrent problems in the international transfer of science and technology. They provide illumination helpful in penetrating the "fog" of technology's social dimension. 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?

Given that the world's technological base is always changing; that technologies were developed in different regions of the world in different historical eras; and that all technologies are inevitably transferred across national and cultural boundaries; we are confronted with a macro-historical driving force behind the cultural changes, dislocations, and shocks associated with technological change.

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."[11] 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 (see Table 1):

Table 1: Four 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.[12]

Mechanisms of Transfer

One obvious mechanism for the transfer of 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 technological transfer between MDCs and LDCs.[13] 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."[14]

Timing of the Transfer

The timing of the transfer is also important. The development of a new principal technology typically follows an S-shaped growth curve.[15] 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 (see figure 1).

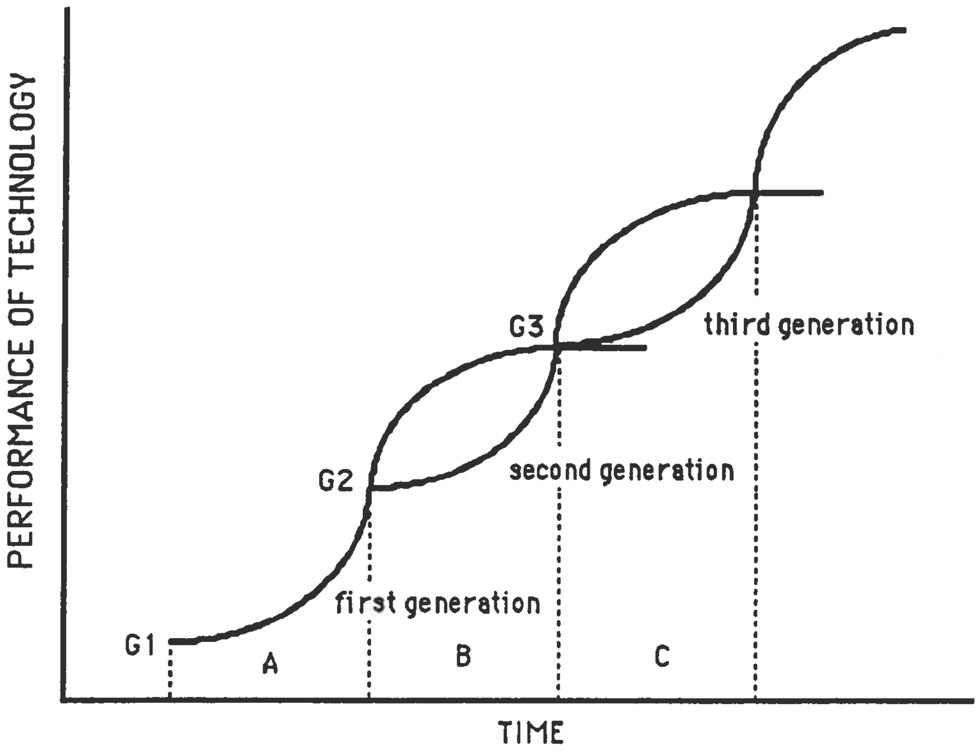

Figure 1: Family of S-shaped curves illustrating growth in performance and timing of transfer for three generations of technology.

Key:

G1: Development of first generation
G2: Development of second generation
G3: Development of third generation
A: Tight control of G1
B: Tight control of G2
Control of G1 gradually loosened
Transfer of G1 initiated
C: Tight control of G3
Control of G2 gradually loosened
Obsolescence of G1
Transfer of G2 initiated

Social and Cultural Impacts

The four levels listed in table 1 treat only the technical and managerial dimensions of technology transfer. An even more complex task, and one for which both the historical and the current literature is very weak, is that of viewing technology as a "socio-technological" phenomenon. In this expanded view, technology transfer involves not only artifacts and human resources, but also cultural, social, and psychological impacts involving human values, beliefs, and other intangibles. These human dimensions are much more complex and unquantifiable than the technical and therefore somewhat simpler aspects of technology transfer.

Rate of Transfer and Novelty of Technology

The process of social assimilation (or rejection) of new technology is also more nation and group specific, and delivers a greater cultural impact than the simple transfer of tools, processes, and managers. This is true because the rate of introduction of a technology into a less developed country is usually much greater than the rate of introduction of that technology <u>within</u> the country where the technology was developed.[16]

For example, the rise of industrial forms of mass production in Britain and the United States proceeded over many decades. Although the social adjustments were both dramatic and at times 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. A study by G. F. Ray 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."[17]

Ray later found that for the cases he studied (Oxygen steelmaking, continuous casting of steel, tunnel kiln brickmaking, shuttleless looms, float glass, and numerically controlled machine tools),

> The new technology gradually replaces the old, but the timing of the replacement and the degree of penetration of the new technique varies a great deal, depending on the nature of the technology, on the economic conditions, such as the stage of development of the country and the economic cycle, as well as on the operators of the technology, the companies that eventually decide on adopting or rejecting the new.[18]

Communication using electricity is an instructive example of a technology that developed over many decades. Experiments with electricity date to Benjamin Franklin's work in the 1760s. In the 1840s Samuel F. B. Morse experimented with the electric telegraph. Soon the major cities of the East were connected by commercial telegraph lines. A transcontinental telegraph line in the United States and a permanent transatlantic cable between Europe and America were completed in the 1860s. Even then a rapid rise in telegraphic communication did not occur until the 1890s and the peak number of telegraphic messages was sent in the 1940s. In the interim, the telephone, radio, television, video-phone, and satellite network of communications were developed within a culture that not only expected instant communications, but whose commercial and military institutions depended on such innovations.

An important aspect of this is the "technological momentum" (a measure of ability to administer a cultural shock) of an innovation, which is a function of both the novelty of an invention and its rate or "velocity" of introduction. The novelty factor refers to the cultural significance of the technology itself; the rate of introduction of the technology was discussed earlier.

As an example, consider again the introduction of electric communication (telegraphy), a highly novel innovation for its time. As William Redfield, a noted scientist exclaimed in 1846:

> "To think of an instantaneous communication between the cities of this great continent!! Well! What next?. . . as a crowning work, electric circulation through space, is now given to human thought!"[19]

In the eastern United States, however, there was no great cultural shock administered by telegraphy. Although Samuel F.B. Morse demonstrated "electric circulation through space" of human thought, there were only two telegraph stations in the world in 1844: Baltimore and Washington. And the information passed along those two notes was tentative and experimental. Commercial telegraph lines soon linked the major eastern cities, but no major cultural revolution ensued.

Compare the difference 30 years later as telegraphy was introduced into the American West. Now the networks were linked to all the cities of the world, to commerce and the military. By 1890 the Indians had been suppressed, the Bison herds decimated, and the frontier was declared closed. For Native American societies that had flourished for 10,000 years, the coming of the telegraph, railroads, etc., brought sudden social dislocation.

Since the quincentenary of the voyages of Columbus is just around the corner, it seems appropriate to mention some examples of technology transfer that were developed gradually in the European nations, but which, when introduced to the natives of the New World, administered sudden shocks to their culture. The examples of grain liquors, firearms, private property rights, and armor all represented sudden shocks to traditional cultures.

Technological "Mass"

In addition to novelty, timing and rate of introduction, a third factor, technological "mass," also influences a culture's ability to accept the shock of a new technology. We may define the technological "mass" of a society as a measure of the size

Conclusion

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 dimension of "social and cultural impacts" especially on non-quantifiable values deserves more attention.

As we have shown, the rate of introduction of a new technological product from one country to another may in fact be strongly related to the impact of the cultural shock administered by the transfer. Defining technological momentum (the ability to administer a cultural shock) as the product of technological novelty and the speed of its introduction into a society, and technological impact as a function of the technological momentum of an innovation and the technological mass of a society provides additional insight. 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 port and capital 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.

A study of history shows that the cultural equilibria of earlier eras have been disrupted by technological innovations. The eotechnic era gave way to paleotechnics and neotechnics. Now, we hope, an ecotechnic era is dawning. Superimposed on this macrohistory of cultures, is the macrohistorical development of each nation and region of the world. As nations pass through formation, growth, and completion of their scientific and technological infrastructures, some have not yet matured (and may never do so); others have passed their zenith and have entered a phase of decline.

The technology we use comes from someplace else. It has been transferred to us either from within or outside our culture. The salients provided by unequal rates of technological development in world cultural history and the histories of particular nations, combined with unprecedented rates of change of technologies, and the dawning of an era of global interaction, promises either a new world civilization or unprecedented social, cultural conflict and ecological disruption.

ENDNOTES

[1] An exception is documented in Klaus Musmann and William H. Kennedy (compls.), Diffusion of Innovations: A Select Bibliography (Westport, Conn., 1989), especially 139-46 on history.

[2] The discussion of eotechnics, paleotechnics, and neotechnics is adapted from Lewis Mumford, Technics and Civilization (1934).

[3] James R. Fleming, "ES 118, the Environment and Society," Colby College, Waterville, Maine, 1991.

[4] It was Herbert Butterfield who endowed the phrase, "scientific revolution" with its modern meaning. See Butterfield, The Origins of Modern Science (1957, revised ed. New York, 1965), 7; and Henry Guerlac, "Science and the Historian," in Essays and Papers in the History of Modern Science. (Baltimore, 1977), 43.

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

[6] This is adapted from James R. Fleming, "Historical Perspectives on the International Transfer of Science and Technology," ICUS XVII Proceedings (1991): 575-85.

[7] 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), 65-93.

[8] See for example, Raymond Phineas Stearns, Science in the British Colonies of North America (Urbana, Ill., 1970).

[9] Both quotes are taken from Leo Marx, "American Literary Culture and the Fatalistic View of Technology," in Leo Marx, The Pilot and the Passenger: Essays on Literature, Technology, and Culture in the United States (New York: Oxford Univ. Press, 1988), 179-207.

[10] A case study of this phase in the United States is Robert V. Bruce, The Launching of Modern American Science, 1846-1876 (New York, 1987).

[11] A. R. Hall, "Early Modern Technology, to 1600," in Melvin Krantzberg and Carroll W. Pursell, Jr., eds., Technology in Western Civilization (New York, 1967), 1.

[12] See Charles T. Stewart, Jr. and Yasumitsu Nihei, Technology Transfer and Human Factors (Lexington, Mass., 1987), 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, 1982), 12ff.

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

[14] H. T. Bernstein, *Steamboats on the Ganges* (Calcutta, 1960).

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

[16] We may formalize this rule as follows:
$\Delta T/\Delta t$ (MDC-->LDC) >> $\Delta T/\Delta t$ (within MDC).

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

[18] George F. Ray, *The Diffusion of Mature Technologies* (Cambridge: Cambridge Univ. Press, 1984), p. 87.

[19] William Redfield to William Reid, July 4, 1846, William Reid's Correspondence with W. C. Redfield, 3 vols., Beinecke Rare Book and Manuscript Library, Yale University, New Haven, Conn.