CHAPTER TWO: THE DIFFERENCES BETWEEN SCIENCE AND TECHNOLOGY

Introduction

In this chapter, there follows a description of what Kuhn referred to as the "profound differences" between science and technology.[1] This is necessary because the two terms are commonly fused together in common usage. It will be demonstrated that science and technology are different both with respect to means and ends. It will be argued that the differences between science and technology are so great that policies which may be good for the development of science may also be bad for the development of technology; conversely, policies which may be good for the development of technology may also be bad for the development of science. Admittedly, the present author pleads guilty to the charge of belaboring the point; but this is necessary. We have so commonly and so sedulously fused the two terms together in everyday discourse that we automatically combine the one and the other together whenever we use them. It is a socially conditioned response; and it is false.

A Description of Science and Scientific Development

Derek Price uses the metaphor of a jigsaw puzzle when describing the growth of basic (fundamental) science. This puzzle began in antiquity, and has been proceeding outward ever

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[1]Thomas S. Kuhn, **The Structure of Scientific Revolutions**, 2d ed. (Chicago: University of Chicago Press, 1970), 161.

since. As he put it,

> The floor is full of spare pieces wanting to be put down and one goes around looking. There are hundreds of thousands of people in the world, some working here and some there, and we are all looking for the next piece to put down. Since there are good rewards for putting down key pieces, everybody is looking very hard. At any given time, anything that can be done reasonably has already been done. So there are no easy pieces; there are not any straight edges left or really odd-shaped bits that are obvious. Occasionally somebody is very clever and puts down a new piece, which opens up possibilities that were not there before.[2]

According to Price, it is impossible to pick up a piece of the puzzle (i.e., "anomalies" in science--pieces of information that do not fit any current or prevailing "paradigm") and put it down unless the puzzle is ready to receive it. "You cannot pick up that piece, hold it in your hand and say 'a hundred zillion dollars for putting that down.' It will not do any good. Either the picture is ready to receive it, or it is not."[3]

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[2]Derek Price, "The Relations between Science and Technology," in **Science and Technology Policies: Yesterday, Today and Tomorrow,** ed. Gabor Strasser and Eugene M. Simons (Cambridge: Ballinger Publishing Co., 1973), 156.

[3]Ibid, 158.

The metaphor of the jigsaw puzzle works well because it conveys the pure excitement of discovery--the intellectual curiosity of scientists--combined with the intelligible view of the universe it produces. This example also implies that work on completing the puzzle has value for its own sake, quite apart from any utilitarian value. It also holds true because it makes sense of the curious phenomenon known as independent multiple discovery, where several scientists independently make the same discovery at roughly the same time, suggesting that the "puzzle" had become ready to receive another important piece.[4] This illustration also rings true because it captures Kuhn's notion of "normal science" as puzzle solving, devoid of any practical application. And it fits Popper's vision of scientific creativity, wherein the scientist forms a hypothesis as an act of intuition (of deductive reasoning), seeking to add to the overall picture, which is essentially an inductive, positivist phenomenon. Lastly, Price's allegory also captures Hagstrom's notion of scientific contributions as "gifts," for which the scientific community rewards donors with esteem and recognition.

[4]See Robert K. Merton, **The Sociology of Science: Theoretical and Empirical Investigations** (Chicago: University of Chicago Press, 1973), 289. He notes that this phenomenon is a "recurrent event in the history of science."

The main point is that the goal of science is not the production of technology: it is the expansion of human knowledge in the attempt to understand the universe. (This is not to say that there is no utilitarian use of science; only that such use is not its goal). Its primary goal is the pursuit of knowledge for its own sake, an expression of the human spirit, as it were. Kuhn argued, for example, that science is essentially non-utilitarian because the dominant scientific paradigm insulates the scientific community from whatever socially important problems are irreducible to the puzzle form, since these social problems "cannot be stated in terms of the conceptual and instrumental tools the paradigm supplies."[5] This is why science has come to represent an ideal, a set of values, and an ethical example of how human affairs could and should be conducted. Moreover, in the secular world of the twentieth century, science performs part of the inspirational function that myths and religions played in the past. For example, although only 21 percent of Americans in 1985 were "attentive" to science (as defined by knowledge, interest, and information consumption), and fewer Americans have much understanding of science, the public overwhelmingly believes in science to bring benefits to humanity.[6] Science has achieved a quasi religious

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[5]Thomas Kuhn, **The Structure of Scientific Revolutions**, 37.

[6]National Science Board, **Science & Engineering Indicators--1987** (Washington, DC: U.S. Government Printing Office, 1988), 140-

status in the West both for its **perceived** utilitarian value and for value as an expression of the human spirit.

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The non-utilitarian goal of science can be clearly seen in the way scientists try to achieve status or other rewards. In science, rewards are given only to the first formal presentation of a discovery to the scientific community. Hence, scientists devote their best efforts toward obtaining and communicating new knowledge.[7] Recognition for priority is "socially validated testimony that one has successfully lived up to the most exacting requirements of one's role as scientist."[8] Moreover, the highest rewards in science are earned not just for priority of discovery, but for the significance of the discovery, and for having lived up to the highest ideals of science in the pursuit of the discovery. Evidence of unethical practices such as "scooping" another researcher (appropriating his work as one's own) or "skimming the cream" (borrowing another's seminal but reasonably well-developed idea) can eliminate a scientists from claims to priority, and can make him/her a social outcast. The successful scientist will have made his contribution according to the ground rules, or the "norms" of science, which Robert

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[7]See Hagstrom, **The Scientific Community** (Carbondale: Southern Illinois University Press, 1975), 69-99.

[8]Merton, **The Sociology of Science**, 293. Hagstrom has further elaborated this point in his ethnographic study of the scientific community. He found that the desire to be first in communicating a new discovery is such that scientists on the "research front" of a given subject (where the puzzle is ready and likely to receive a new piece), who are at the cutting edge of new boundaries of knowledge, often fear getting "scooped" by a colleague (where one scientist publishes a discovery before another is able to do so).

Merton described as four basic institutionalized "norms"--universalism, communism, disinterestedness, organized skepticism--which together comprise the ethos of modern science.

Universalism is rooted deep in the impersonal nature of science: the acceptance or rejection of claims does not depend on the personal characteristics of those who espouse them. The nationality, race, religion, or ideology of a given scientist have no bearing on the quality of his or her work. The norm of communism refers to imperative of full and open communication of scientific findings: "Secrecy is the antithesis of this norm; full and open communication its enactment." Even though the suppression of a scientific finding may serve no ulterior motive, "the suppression of scientific discovery is condemned." The norm of disinterestedness refers to the idea that scientists are prevented from bring their own subjective views and passions into their work. They may hold such passions privately; but they sedulously withhold them from their work. Merton says that, "by implication, scientists are recruited from the ranks of those who exhibit an unusual degree of moral integrity." In practice, the norm of organized skepticism insures that the cleavage between the sacred and the profane,

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Ibid, 274.

Ibid.

between subjects which require uncritical respect rather than objective analysis, are not preserved. Hence, "conflict becomes accentuated whenever science extends its research to new areas toward which there are institutionalized attitudes or whenever other institutions extend their control over science."

The point to be made about these "norms" of science is they describe the professional socialization of scientists, which puts a premium on the expansion of the frontiers of human knowledge, devoid of any notion of utilitarian value. The prevalence of these lofty ideals and norms in science is so pervasive that the vast majority of scientists would assert there is no problem of deviation in science, in stark contrast to Broad and Wade's contention to the contrary. Hagstrom observed that the socialization of scientists in the ethos of

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Ibid, 276.

Ibid, 278.

William Broad and Nicholas Wade, **Betrayers of the Truth: Fraud and Deceit in the Halls of Science** (New York: Simon & Schuster, Inc., 1982). It is worth noting here that Broad and Wade--though intelligent and highly persuasive--fail miserably to document their thesis that fraud is rampant in the halls of science. Broad and Wade attacked sociologists like Robert Merton, who portray science as "a band of colleagues dedicated to a common goal, the pursuit of truth." They argue to the contrary that science tends to produce an elite whose rewards come not only from the merits of their work, but from their place in the hierarchy. While it is true that science produces an elite, it is also true that this elitism, for all its faults, is based squarely upon merit, not position. Broad and Wade can muster only six scant pages of their appendix--from the second century B.C. to the present--to document cases of fraud in science. They ask the readers to send them information on fraud science tends to produce persons who are so strongly committed to the central values of science that they unthinkingly accept them. "Research as an activity comes to be 'natural' for them: they find it self-evident that persons should be excited by discoveries, intensely interested in the detailed working of nature, and committed to the elaboration of theories **that are of no use whatever in daily life.** They develop a vocabulary of motives that makes curiosity about nature and an interest in understanding it an intrinsically important component of the human personality."

These norms of science are so strongly internalized and so sedulously verified (fraud will sooner or later become discovered) that the institution of science is of necessity self-governed and regulated. Science is a socially insular institution: Attempts to impose on scientists a doctrinaire or predetermined view of the universe ultimately forces scientists to become non-scientists. Although it is true that scientists often perform "boundary-work" (the job of demarcating science from non-science) in ways contrived to enlarge their material and symbolic resources and to defend their professional autonomy, the scientific community is the only society capable

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to further embellish their appendix.

Hagstrom, **The Scientific Community**, 9. Hagstrom makes the interesting point that various antirationalist philosophers such as Nietzsche viewed the cultivation of "disinterestedness" as a form of psychopathology.

of doing such work. Any fraud or self-deception in science (such as the famous case of "N-Rays") ultimately has to pass three formidable hurdles: the verifiability of scientific claims (experiments must be successfully replicated); the peer review process (rewards are given to the best ideas with the clearest evidence of the ability to carry them out); and the cognitive structure of science (the hierarchical system of knowledge in which the multitude of observable facts are reduced to underlying laws, which are further reduced to theories which explain the laws). Science is therefore fundamentally unlike other social institutions which require external regulation: science functions best if left alone to do its own house-cleaning.

Independence from social and other controls is a necessary prerequisite for the growth of science. Self-government is required for the maintenance of a framework of institutions that enable mature scientists--thoroughly socialized in the norms of science and selected by the scientific community itself--to perform independent research. The spontaneous growth of science thus demands that researchers be free "from all temporal authority." It is true that the overriding fact about science is its autonomy: It is autonomous in the decisions about what

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Michael Polanyi, **The Logic of Liberty** (Chicago: University of Chicago Press, 1980), 40-41. Polanyi's chapter 4 is an excellent essay on self-government of science.

research would be undertaken, in the debates about what types of knowledge are valid, and in the recognition of achievement and the granting of status and esteem. Autonomy is the heart of both the ethos and the organization of science. This is well-put by Hagstrom:

> Basic science is unlike other professions in that its practitioners not only claim autonomy in determining procedures to be used in the course of the work and in evaluating the success of these procedures; they also claim the right to decide for themselves the problems they should select and, on the basis of their work and that of others, whether or not theories are true. Other professionals may sometimes claim such rights, but these rights are less integral to their tasks than to those in basic science.

The negative aspect of the autonomy of science is that scientists, intent on maintaining their professional autonomy, occasionally perform technically unnecessary "snow jobs" on others; for example, sometimes scientists give the impression that their tasks are highly complex and almost incommunicable to others, when the tasks may in reality be simple and easy to understand. Hagstrom notes: "Workers behave this way to maximize their autonomy, something most [scientific] workers

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Hagstrom, **The Scientific Community**, 108.

value, and to increase their power over clients and others." The noted arrogance of some scientists--their disdain for the "unwashed masses"--is an unfortunate consequence of the very real need for professional autonomy. Kuhn has noted that the "unparalleled insulation" of scientists from the laity gives science the appearance of a new priesthood; but fortunately for the scientist, he is not like engineers, doctors or even theologians, because "the scientist need not choose problems because they urgently need solution."

A Description of Technology

Very simply, technology consists of two things: an artifact and a procedure. It can be one or the other, but it is usually both. In common usage, "technology" refers to artifacts such as computers and industrial machinery; but a full description of "technology" includes both the "artifacts" and the "procedures." Put together, technology (the artifact and the technique) can be defined as "the organization of knowledge

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Ibid, 108.

Kuhn, **The Structure of Scientific Revolutions**, 164.

Joseph Berliner, **The Innovation Decision in Soviet Industry** (Cambridge: The MIT Press, 1976), 1. See also Dennis S. Mileti, David F. Gillespie & Elizabeth Morrissey, "Technology and Organizations: Methodological Deficiencies and Lacunae," **Technology and Culture** 14 (January 1973): 84. According to Mileti et al, "technology might be defined as the types and patterns of activity, equipment and materials, and knowledge or experience used to perform tasks." 84

for practical purposes." It is only with this broader definition of technology that one can understand the impact of technology on society, institutions, and human values--and vice versa. Otherwise, "its pervasive influence on our very culture would be unintelligible if technology were understood as no more than hardware." As one author put it, technology is the combination of both "hardware" and "thoughtware."

Artifacts are the machines themselves; for example, in the steel industry, they are the blast furnaces, the rolling mills, and the foundries. This is generally well known and understood. The procedures, on the other hand, "are the ways in which the equipment and materials are used in the production of the outputs." Taylorism (otherwise known as "scientific management") falls under the category of "procedure." Likewise, a recipe for baking bread is a procedure (or technique). There are techniques for driving a car, for operating lathes, for programming computers, for splicing genes; and the activities of all social institutions are conducted by means of techniques. Hence, technological progress is not merely the introduction of

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Emmanuel G. Mesthene, "The Role of Technology in Society," in **Technology and Man's Future**, ed. Albert H. Teich (New York: St. Martin's Press, 1972), 129.

Ibid, 130.

Rosalia Berbekar, "Hephaestus--The God We Love to Hate," **Bulletin of Science, Technology and Society** 8 (1988): 175.

Ibid.

newer and more efficient artifacts (machinery), but includes both "the advance of the technological knowledge contained in society" and "the improvement of the technology (artifacts) actually employed in production." Hence, when one speaks of technological development, one is also speaking about social and economic development.

The Differences between Science and Technology

Typically, whenever one points to the usefulness of science, one includes **science with technology.** Yet science and technology, as mentioned in the introduction, are profoundly different enterprises. Here is how Derek Price described the differences between the two: science is impervious to economic, moral, or ideological inducements, while technology is not. As he put it, "technology is what one is paid to do: science is what one acquires title to by giving it away, that is, publishing. Science proceeds with regularity in war and peace; the pace of technology fluctuates substantially." Langdon Winner likewise noted that, if one examines the actual activities of scientists, one finds them working to make sense

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Ibid.

Price, "The Relations between Science and Technology," 149. See also Derek Price, **Little Science, Big Science** (New York: Columbia University Press, 1963), 18. Actually, science does not proceed with regularity in war and in peace. The number of scientific papers published annually continued to grow during World War II, but the rate of growth of scientific papers declined.
However, the same rate of growth resumed after the war.

of universal laws, and to make progress on what are very often limited topics of research. Technologists (engineers), on the other hand, spend most of their time searching for solutions to very specific, often mundane, **practical** problems. At the risk of belaboring the point, a quote from an economist, Gerhard Rosegger, sums up the difference between science and technology quite well: "While the essence of technology is application, science involves pure information, itself devoid of any practical uses, least of all in the conversion of inputs into outputs. **The objective of scientific activity is discovery; the objective of technological effort is productive results.**"

Yet it is commonplace to equate science with technology. Originating with Sir Francis Bacon, the utilitarian view of science as an instrument of control over nature has become so commonplace that few people seriously question the correctness of this view. Bacon--the first to systematically formulate the idea that science is useful in subduing and controlling nature, not just in understanding it--argued in **Novum Organum** that "the true and lawful goal of the sciences is none other than this:

Langdon Winner, **Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought** (Cambridge: The MIT Press, 1977), 117.

Gerhard Rosegger, **The Economics of Production and Innovation: An Industrial Perspective** (New York: Pergamon Press, 1986), 5. For a clear, pellucid delineation of the differences between science and technology, see Mario Bunge, "Technology as Applied Science," **Technology and Culture** 7 (Summer 1966): 329-331.

that human life be endowed with new discoveries and powers." He thought that the union of "science" with the "practical arts" had given the world three revolutionary inventions (the printing press, gunpowder, and the magnet) which made political accomplishments pale by comparison. "For these three have changed the whole face and state of things throughout the world, insofar that no empire, no sect, no star seems to have exerted greater power and influence in human affairs than these mechanical discoveries."

We have come to accept the utilitarian view of science as the harbinger of technology because there is a certain amount of truth to it: science **does** help us understand the fundamental natural forces we manipulate in our use of technologies. As a consequence, over time the distinctions between science and technology have been blurred. And the resulting confusion is reinforced by well-meaning (but incorrect) scientists who ask the government for money. Invariably, the sales pitch includes promises of technological applications. This causes much confusion, because when the government wants to control the communication of scientific research, or possibly direct the direction of research toward the solution of practical problems, scientists assert the truth of the matter that science has

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Winner, **Autonomous Technology**, 21.

Ibid, 22. Actually, it was not science which produced these inventions, but trial and error technological research.

nothing to do with technology, and that one can not direct the direction of basic research toward practical ends. Although the two assertions are not necessarily contradictory (basic science often **can** be "used" by technologists, and one can not efficiently guide the direction of basic research toward the solution of practical problems), it does illustrate the very complicated relationship between science and technology, and the degree to which the differences between the two have been obfuscated.

The act of creating technology is fundamentally different from the act of creating scientific knowledge. In the first place, the scientist is autonomous from outside direction, following the internal logic of scientific development. As noted in the previous section, scientists work best when left free from outside interference. Although engineers and technologists are trained in the sciences, typically their work is not aimed at producing knowledge for the sake of knowledge. Rather, they place their skills at the disposal of managers, who may not only select their problems, but may also select their methods and define the adequacy of problem solutions.

William Kornhauser provides a good example of the profound

Thomas F. Gieryn, "Boundary-Work and the Demarcation of Science from Non-Science: Strains and Interests in Professional Ideologies of Scientists," **American Sociological Review** 48 (1983): 781-795.

Hagstrom, **The Scientific Community**, 150.

differences between scientists and technologists with respect to the matter of autonomy. In his study of scientists in industry, he found that the transition from seeking knowledge for knowledge's sake to doing "applied" research is very difficult. Usually, the scientists have to become "re-socialized" to work in industry. In research organizations devoted to basic research (usually universities), scientists have freedom in their choice of projects. But in industrial organizations, "such freedom is not usually permitted." Thus, "the more strongly the research worker is oriented to the scientific world, the more acutely will he feel the conflict." This causes institutional friction between science as a profession and industrial management--with the latter having the final say on technological and scientific matters.

One of the main problems of science in industry, for example, is to get those who are trained to do basic research to pay attention to practical matters--in short--to become engineers, since engineers "are more likely than scientists to take account of business interests." In industry, scientists "must be made to realize that their own appreciation of the need for de-emphasis at a given time in their own field is also an

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William Kornhauser, **Scientists in Industry** (Berkeley: University of California Press, 1963), 62.

Ibid, 80.

Ibid, 65.

expression of **their worth to the organization. . .** It means men must be taught to appreciate the need for dropping work at an interesting phase **from a scientific standpoint.**"

Scientists in industry tend to feel that their professional integrity is threatened by the constant pressure to "come up with something." They try to protect their autonomy by appealing to the norms of pure science, "a defense against the invasion of norms which limit directions of potential advance and threaten the stability and continuance of scientific research as a valued social activity." This struggle causes management considerable angst, because business managers with no experience in engineering find their traditional methods of calculating the economic payoff of research inapplicable. And scientists point out that professional performance is not open to simple judgments of success or failure, that there is a large element of uncertainty in any project, and that important discoveries are of necessity much larger than problems which are certain of solution. Management can never be sure whether the scientist is putting on a typical "snow job" in order to preserve his treasured autonomy, or whether the scientist in

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Ibid, 70. See also Hagstrom, **The Scientific Community**, 31. He notes that scientists do not like being "downgraded" to do the work of technologists or engineers.

Kornhauser, **Scientists in Industry**, 26.

question is really developing a creative new idea. As a result of the differing orientation toward ends of research (practical application or knowledge), engineers are more likely than scientists to be entrusted with leading R&D, since they "they are more likely than scientists to take account of business interests."

Secondly, the system of rewards for doing science and for doing technology are vastly different. Whereas scientists are keen to be the first to communicate a new finding (since this is the basis of status and recognition, the highest rewards in science), technologists tend to protect their secrets. Like the scientist, the technologist (commonly called an "applied scientist," a misleading term for reasons presented below) expects to receive status and recognition for his achievements; but pecuniary remuneration is the main motivation. Unlike scientific property, which is acquired by giving it away in open

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Kornhauser reports that, in order to solve this dilemma, industrial research departments allot approximately 10 percent of their time to work on projects of their own choosing, but otherwise he is expected to work on projects assigned to him by the organization.

Kornhauser, **Scientists in Industry**, 65. According to Kornhauser, the best way of ensuring that scientists take the firm's interest to heart is by placing the scientists in constant contact with the firm's clients. "It does get the people who are
too strongly in basic research to pay attention to other things." p. 67

publication for all the world to see, technological property has market value and is therefore protected by patents, copyrights, licenses, and so on. Unlike scientific discovery, where there is great competition to be the first to communicate a new discovery (which is built into the reward system of science), in the development of new technologies, discoveries are usually protected against competitors. This is why the Supreme Court ruled in the case of **U.S. v. American Bell Telephone Company** that "the inventor is one who has discovered something of value. It is his absolute property. He may withhold the knowledge of it from the public." Archetypically, firms and corporations which rely on innovation as a way of developing its products more smoothly and efficiently (and

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Price, "The Relations between Science and Technology," 159. "You can only acquire scientific property--intellectual private property--by open publication. The more open the publication, the more private is your property. If you keep it to yourself somebody else will discover it, and then it is not yours at all."

For a good description of the legal and institutional barriers to the transfer of technology from one company to another, from one nation to another, see A. Coskun Samli, **Technology Transfer** (Westport: Quorum Books, 1985).

See Robert K. Merton, "Priorities in Scientific Discovery," **American Sociological Review** 22 (December 1957): 635-659. Science offers enduring fame to those who are successful, by virtue of the fact that the discoveries in question are named after the discoverer, i.e., Newton's laws, etc. Scientific discovery requires both originality and creativity, thus awarding those who have exceptional ego strength.

Quoted from Merton, **The Sociology of Science**, 275.

hence, more profitably) consider their technology (know-how) as proprietary and protect it as a trade secret.

A third difference between science and technology has to do with patterns of communication among professional colleagues. Due to the economic value of certain technologies, there are many restraints on the communication of new technologies, since they have often been developed with large expenditures of time, money, and commercial risk. Like scientists, engineers in competing firms do communicate with each other, and even exchange information; but the line is drawn between vital and non-vital information from the standpoint of competition. Von Hippel's study of communication patterns among technologists

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This applies not only to the development of new equipment, but also to the development of new procedures as well. See for example, Marvin B. Mandell, "Monitoring and Evaluating New Managerial Technologies," in **Technology Transfer**, ed. A. Coskun Samli (Westport: Quorum Books, 1985), 264. New managerial technologies are frequently the application of social sciences to problems in industry.

See James R. Basche, Jr. and Michael G. Duerr, **International Transfer of Technology: A Worldwide Study of Chief Executives** (New York: The Conference Board, Inc., 1975), 5-6. The sellers of technology typically price their technology very high, for a couple of reasons: first, it has been expensive to obtain; second, and most important, in selling technology through licensing or other agreements, the seller may part with a small or large part of his own market.

See Donald C. Pelz and Frank M. Andrews, **Scientists in Organizations: Productive Climates for Research and Development** (New York: John Wiley and Sons, Inc., 1966), 38. Like Ph.D.'s in academic research, the most productive and innovative engineers are those who communicate with their peers several times a week. In general, the higher the frequency of communication, the higher the productivity.

found that engineers establish their own professional networks of colleagues in competing firms, and that these networks are mutually beneficiary. But these networks stop far short of the standards for science in communicating findings; for example, if engineer A has a problem about which engineer B knows something, engineer A asks B for advice. Then engineer B makes a judgment as to the competitive value of the information A is requesting. "If the information seems to him vital to his own firm's competitive position, B will not provide it. However, if it seems useful but not crucial--and if A seems to be a potentially useful and appropriately knowledgeable expert to who may be of future value to B--then B will answer the request as well as he can and/or refer A to other experts." By contrast, even scientists who are concerned about being "scooped" communicate freely their findings with their colleagues, since the more open the communication, the easier it is to establish priority.

A fourth difference between science and technology--perhaps

Eric von Hippel, **The Sources of Innovation** (Oxford: Oxford University Press, 1988), 77. Kornhauser found much the same as Von Hippel. He reported that his investigations showed "quite clearly" that engineers were less likely than scientists to communicate with other professionals. "Among scientists, fundamental researchers are more likely than applied researchers to feel that free communication is important, and establishments usually permit a larger proportion of fundamental research than of applied research to be published." p. 75 Kornhauser adds that in Great Britain, it is estimated that only 0.1 percent of the results of technological research are published there.

the most important difference of all--has to do with methodology. Scientists, of course, rely on scientific theory as a guide to their work. Technologists, on the other hand, rely minimally on scientific theory as a guide to their work.

For example, David Collingridge studied two classic examples of how scientific theory allegedly provides the lead for new technology, the development of Lister's antiseptic surgery and Fermi's atomic pile. Contrary to the science textbook versions, he found that scientific theory played a small role in the development of both technologies. Unlike popular notions of scientific theory guiding technological research, in the creation of antiseptic surgery and controlled nuclear fission, the research process of these technologies consisted primarily of informed trial and error. Moreover, Collingridge showed that there are two main problems with technological research that is highly sensitive to scientific claims: first, the claim may be wrong, pushing R&D effort into an unfruitful blind alley; second, the scientific theory may be undeveloped, forcing technologists to wait until such theories become well articulated, precise, highly universal, and simple. Successful innovation, which relies on the incrementalist approach based on simple trial and error allows more rapid and

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David Collingridge, "Incremental Decision Making in Technological Innovation: What Role for Science," **Science, Technology, & Human Values** 14 (Spring 1989): 141-162.

extensive learning.

Collingridge's findings that very few technological innovations depend upon scientific knowledge are supported by other empirical studies. For example, in a study of successful technological innovations, Michael Gibbons and Ron Johnston found that only 36 percent of these innovations "used" or needed inputs of scientific information. Moreover, a very small percentage of such information relied upon scientific theory: the bulk of these inputs of scientific information consisted mainly of information on such commonplace matters as the properties, characteristics or composition of materials and components. Scientific theory played a much smaller role than expected, and basic scientists were most useful to the "problem solvers" in translating information in scientific journals into a form meaningful to the problem solvers.

Mario Bunge's study of innovation offered an explanation for the relatively low input of scientific theory into technological research. As he explained it, the accessibility of scientific knowledge to the development of new technologies is often of very little direct use because "the relevant variables are seldom adequately known and precisely controlled.

Michael Gibbons and Ron Johnston, "The Roles of Science in Technological Innovation," **Research Policy** 3 (November 1974): 229-236.

Real situations are much too complex for this." Since the technologist is interested in efficiency and not necessarily the truth, in getting things done rather than in gaining a deep understanding of them, "deep and accurate theories may be impractical; to use them would be like killing bugs with nuclear bombs."

Indeed, imposing the norms of scientific research upon the norms of technological research can be detrimental to technological research. For example, Mark Azbel (former departmental director of the prestigious Landau Institute of Theoretical Physics in the USSR) said that "The Soviet scientist does what he can in the way he should, and the American . . . does what he should in the way he can. That is, in the Soviet Union you have a very strong tendency to be very accurate, very profound . . . But American scientists . . . try to develop ideas . . ." Whereas in the USSR the Soviet scientist tries to do his work "perfectly," American scientists "aren't very well founded but are very novel." American scientists are admittedly

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Mario Bunge, "Technology as Applied Science" **Technology and Culture** 7 (Summer 1966): 335. This statement accords with a statement made by my former physics professor. He said that if one could know all of the variables involved in a single event, one could accurately predict the outcome; but the problem is in gathering the plethora of relevant variables.

Ibid.

Gary Taubes and Glenn Garelik, "Soviet Science: How Good Is It?" **Discover** (August 1986): 49.

Ibid.

"less profound," but the payoff is that they are "more inclined, more forced, to do something really new."

The historical role of scientific theory in technological development has been minimal. For example, Price points out that two modern technologies--radio and photography--went through a whole generation of developments at the hands of "backroom tinkerers," that is, those who not only knew little or no science, but who who "knew no technology either." He further adds that the modern perception of experimenters and innovators working in scientific laboratories is ahistorical, barely representative of the true history of innovation. And his findings dovetail quite nicely with the findings of Langrish et al, who noted that the educational backgrounds of successful innovators are extremely varied. Even where the contribution of an individual has been predominantly technical, "the person does not always hold high formal qualifications in science or technology." Indeed, Langrish et al were struck, as they put it, by the frequency of innovation coming from those who are not "qualified manpower" according to the categorization of the British Committee on Manpower Resources for Science and

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Ibid.

Price, "The Relations between Science and Technology," 154.

J.M. Langrish, W.G. Evans and F.R. Jevons, **Wealth from Knowledge: A Study of Innovation in Industry** (New York: John Wiley & Sons, Inc., 1972), 18.

Ibid.

Technology. For example, of the five member team which created high voltage transistors for the Lucas electrical company, only one had university training; the rest had been self-educated, or trained on the job.

Even in mundane technological problems, scientific theory can be more of a hindrance than a help. Hence, Bruce Seely's study of highway engineering revealed that experimental methods usually considered typical of science "hindered the development of practical answers to engineering questions while failing to enhance theoretical understandings of the problems under investigation." Likewise, Collingridge argues that germ theory and antiseptic surgery evolved not from the pure scientific speculation of Pasteur, but from the accumulation of dozens of largely unrelated generalizations from painstaking experiments. In such instances, practice was the guide to theory, not vice-versa. Hence, Fermi and his colleagues at the University of Chicago studied radioactive decay "experimentally," with little

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Ibid. Here are some examples which Langrish et al provide: "Lowe, whose artistry in fashioning silicon contributed to the development of high-voltage transistors by Lucas, had no university training. Ransom of Short Bros has no formal engineering qualifications but as design draughtsman contributed to no less than eight out of eighteen patents taken out on the Seacat missile system. Sir James Martin holds over a hundred patents but has no formal qualifications."

Ibid, 338-344.

Bruce E. Seely, "The Scientific Mystique in Engineering: Highway Research at the Bureau of Public Roads, 1918-1940," **Technology and Culture** 25 (October 1984): 799.

guidance by theory. Moreover, "even today there is insufficient theoretical understanding of why a uranium atom undergoes fission the way it does." Furthermore, the theoretical errors in understanding the atom at the time "did not prevent the technology from working: The technology of the pile was not sensitive to atomic theory." For these and other reasons, Price quite accurately declared that the vast majority of new technologies owes little or nothing to "science": "I must make the point that in spite of superstition to the contrary, **most technology has absolutely nothing to do with science.**" As Bunge pointed out, this fact should not disturb us: we continue doing

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Collingridge, "Incremental Decision Making," 157.

Ibid.

Price, "The Relations between Science and Technology," 164. Price cites as an example Marconi's invention of radio long after Clerk Maxwell's breakthrough in understanding electromagnetic waves: the invention of radio "came from a tinkering with scientific theory that was already so old that Marconi did not know it, let alone use it." In fact, Price asserts that Marconi could not solve an electromagnetic field equation to save his life. Instead, we see in the actual history of radio a bunch of back-room tinkerers. See also Stephen Davies, "Diffusion, Innovation, and Market Structures," in **Research, Development, and Technological Innovation**, ed. Devendra Sahal (Lexington, MA: Lexington Books, 1978), 172. New technologies rarely spring "like Minerva from Jove's forehead." Rather, he says, new technologies are the results of countless modifications of earlier, less specialized designs. "Success in engineering comes primarily from 'getting one's hands dirty' rather than from conceptualizing alone." Others have noted the intuitive aspect of technological creativity, suggesting that new technologies are not the product of scientific reason alone. There are many historical case studies which verify this point. See for example Alexander Keller, "Has Science Created many things without understanding how, and we know many processes which are practically useless.

A fifth difference between science and technology is in the difference between scientific and technological progress. Scientific revolutions occur when a brilliant scientist formulates a better way of understanding the universe, one which makes sense of the numerous and troubling "anomalies" encountered in the process of "normal" science. Scientific revolutions are the dramatic appearance of a new, more powerful theory. Such was the impact of Einstein on the scientific community, as was Newton's before him. One can see the impact of these revolutions very clearly by virtue of the fact that citations of papers belonging to a displaced paradigm virtually cease, whereas the works which establish new theories become the foundation of entirely new citation patterns.

By way of contrast, technological revolutions come incrementally in "clusterings." New technologies are frequently made possible by the creation of other related or completely unrelated technologies. For example, the development of the jet engine was known to be theoretically possible for some time before the creation of high-grade alloys made it actually

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Technology?" **Minerva** 22 (Summer 1984): 160-182.

Kuhn, **The Structure of Scientific Revolutions**, chapters 6-13.

See Derek Price, "Networks of Scientific Papers" **Science** 149 (July 1965): 510-515. One can also see this at work on small possible. Likewise, the soldering of aluminum--necessary for the manufacture of jet aircraft--depended on advances in radio-frequency techniques. These incremental advances called "clusterings" make it very difficult to separate technological advance from culture and the market. "Furthermore, most of technological and economic progress is not the result of major breakthroughs to radically new conceptions but rather of the journeyman efforts of thousands of anonymous invention workers." Indeed, technologies depend upon one another and interact with one another in ways which are not apparent to the casual observer, "and often not to the specialist." Clearly, it is impossible to plan the thousands of small-scale innovations which are necessary for the emergence of major technological achievements.

A sixth difference between science and technology is the difference between producers and consumers of knowledge. When

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scale revolutions as well.

C.F. Carter and B.R. Williams, **Industry and Technical Progress** (London: Oxford University Press, 1957), 20.

Rosegger, **The Economics of Production and Innovation**, 112.

Ibid, 26-27. See also William Vincenti, "Technological Innovation without Science: The Innovation of Flash-Riveting in U.S. Airplanes 1930-50," **Technology and Culture** 25 (July 1984): 540-576. Flash-riveting was one of many **production-centered innovations** which were in widespread use throughout the history of the aircraft industry. This pattern, Vincenti notes, is very different from the model of innovation from scientific discovery or trial and error R&D which has occupied the attention of historians and economists.

the development of technology **is** based upon fundamental science, technologists **use** such knowledge (they don't produce it themselves) to create products or processes. One must hasten to add that historically, the translation of fundamental research into useful technology has been a matter of accident, what Merton called "serendipity," "a serendipity that was encouraged and nurtured but was not more assumed than planned."In such cases where technologists depend upon scientific knowledge, here is how the process works: "New science is created by university researchers seeking knowledge with little heed to practice. Industrial scientists use that understanding to work on what will likely enhance their company's profits, with little heed to advancing general knowledge." Another writer put it this way: "Scientists see patterns in phenomena as making the world understandable; engineers also see them as making the world manipulable."

In other words, those who do basic science produce the intellectual tools which engineers may (or may not) use to help make new technologies. Unlike the academic or basic scientist--

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Frank Newman, **Higher Education and the American Resurgence** (Princeton: Princeton University Press, 1985), 119.

Richard R. Nelson, "What is Private and What is Public about Technology?" **Science, Technology & Human Values** 14 (Summer 1989): 232.

American Association for the Advancement of Science, **Science for All Americans** (Washington, D.C.: American Association for the Advancement of Science, 1989), 40.

who pursues knowledge for its own sake--the "applied" researcher does his work with his eyes fixed on possible future applications. Hence, in cases where science is applicable to technology, it is "the substratum upon which today's technology is built." In cases where scientific information is crucial to the development of new technologies, engineers "use" scientific knowledge (together with strategies of design) to solve practical problems. In such cases, engineering is "the systematic application of scientific knowledge," not the of knowledge for its own sake. Price refers to science as a "sort of distilled juice" which keeps the medium of technology straight. With respect to technology, science is merely "an unbiased discipline to be used as man will."

Carter and Williams, **Industry and Technical Progress**, 18.

Ralph E. Lapp, **The New Priesthood: The Scientific Elite and the Uses of Power** (New York: Harper & Row, 1965), 212.

American Association for the Advancement of Science, **Science for All Americans**, 40.

Ibid. This idea that technologists and engineers methodically use scientific knowledge in their trade (from whence the term "applied science" comes) has become a bit of a cliche, a bit too overworked. As mentioned above, technological development, where successful, is rarely tied strongly to scientific theory.

Price, "The Relations between Science and Technology," 166.

Ibid, 218. See Robert Reich, "The Quiet Path to Technological Preeminence," **Scientific American** 261 (October 1989): 42. He notes that in 1986, America's trade balance in high-technology goods turned negative for the first time in modern history. He argues that there is little reason to believe that investment in the development of science will help American industries become

The technologist may in the course of research and development discover new scientific information; but this is not his primary goal. Rosegger noted that private firms (most notably, Bell laboratories) commit resources to basic research when the existing scientific information poses barriers to the pursuit of technological objectives; although this is fundamental research, it is not the search for knowledge for its own sake, in alignment with the ethos of basic science. In these cases, the research typically has some potential for application as its ultimate goal. "To the profit-seeking firm, discoveries are but a by-product of its quest for private gain." When scientists working as engineers in industry make a new scientific discovery, they usually communicate the discovery (usually to enhance the prestige of the company) only **after** the application of such knowledge has been patented and put into production (or abandoned as economically unfeasible).

The seventh distinction between science and technology is the difference in requirements for accuracy. Whereas in technology "a rough and simple theory supplying quick correct

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more technologically competitive: "The problem lies in the inability of American companies to transform [technological] discoveries quickly into high-quality products and into processes designing, manufacturing, marketing and distributing such products."

Rosegger, **The Economics of Production and Innovation**, 6.

Kornhauser, **Scientists in Industry**, 77. Publications may raise the prestige of the establishment, and hence "improve the market estimates of orders of magnitude very often will suffice in practice," these standards are far below those prevailing in basic research. Whereas in scientific research work, the failure of a given scientific prediction can be fed back into the theory responsible for it, thereby improving it, "in the case of expert knowledge there is no theory to feed the failure into." Expert prognoses in technological problem-solving are typically made "with shallow but well-confirmed generalizations" which "are preferable to risky scientific predictions."

A final distinction between science and technology is the difference between scientists and technologists with respect to creativity. Kuhn and others have presented evidence to suggest that creativity is not a function of "normal" puzzle-solving science.

Conclusions

If Kuhn is correct in suggesting that there are "profound differences" between science and technology, and if the above essay reasonably accurately depicts the differences, then one might apply an understanding of these differences in the formulation of national technology and science policies. For example, one might apply these differences to the current

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for the firm's products and its capacity to acquire capital."

Bunge, "Technology as Applied Science," 334.

Ibid, 345.

Ibid.

problem of intellectual property rights which has developed in the wake of the recent "University and Small Business Patent Act" of 1980, which gave universities ownership of patent rights to technology developed in universities with government funding.

The nub of the matter is in labelling technological research as fundamental research, and in treating patentable discoveries as purely scientific information. But if one examines the funding of research in American universities, federal support for "applied" projects outnumbers "basic" projects by four to one. And these figures do not include the growing private (corporate) support for proprietary R&D which goes on at American universities. Yet, both basic and technological researchers at American universities have traditionally included technological research under the rubric of "science." It might be more accurate to describe American universities as institutions devoted to technological research with basic research conducted ancillary to this endeavor.

National Science Foundation, **Federal Support to Universities, Colleges, and Selected Nonprofit Institutions (Fiscal Year: 1986)** (Washington: National Science Foundation, 1988), 9-28. See also Congressional Budget Office, **Federal Support for R&D and Innovation** (Washington, D.C.: U.S. Government Printing Office, 1984), 23-25. Federal funds provide approximately 70 percent of all university support for technological projects, of which amount over 85 percent is devoted to projects for the department of defense, the Department of Energy and NASA. Industry support for university R&D was less than 10 percent.

See for example Raymond J. Woodrow, **Management for Research in**

The staunchest defender of the former policy of free and open communication of technological research is the National Academy of Science (NAS), which predictably defends the norm of science for free and open communication. However, in defending the right of scientists to full and open communication of basic research, the NAS may be missing the point: The issue is not science, it is technology. Whereas free and open communication is the norm of science, **competition** between various proprietary designs is essential to technological innovation.

On the other side of the debate, the federal government has

U.S. Universities (Washington, D.C.: National Association of College and University Business Officers, 1978), 35. He notes that technological problem solving in universities "probably has little place a university under the rubric of research, although other considerations such as furtherance of the public interest and public welfare may fully justify its existence." See also Joseph Ben-David, **The Scientist's Role in Society** (Chicago: University of Chicago Press, 1971), 143. Ben-David noted that the American university pioneered "applied" or "problem oriented science." There is no doubt that historically, "this country's greatest strength has been not in research, but in technology." As Ben-David pointed out, "The most conspicuous and successful instance was the development of clinical research in medicine at Johns Hopkins University. Instead of emphasizing the invidious difference between basic and clinical research, attempts were made to create university hospitals with conditions that approximated as nearly as possible the conditions of an experimental laboratory and to use these facilities for the improved training of physicians." Similar policies were pursued in agriculture, education, and other fields. Hence, in the U.S., universities considered it their job to create a "research basis" in the service of their practical professions, rather than creating professions in the service of basic research.

See Science, Technology, & Human Values, "The NAS Report on Scientific Communication and National Security: Excerpts," **Science, Technology, & Human Values** 8 (Winter 1983): 18-20.

been strongly in favor of patenting technologies created by universities, especially where government funding is involved. The government has pointed out that patenting technology **is** free and open communication: patents by necessity spell out the mechanics of technologies in order to protect individual rights. And the revenue which the patents generate is a welcome source of income for universities at a time when the federal budget under stress. Indeed, Steven Muller, President of Johns Hopkins University, argues that industry support will be an **essential** source of revenue for American universities: "Only the trinity of university, industry, and government can effectively support the trinity of service, training, and research."

This trinity of university, industry and government has been getting steadily stronger in the last decade. For example, Charles Caldart's article on industry investment in university research gives numerous examples of the growing ties between industry and university. MIT received $120 million from the Whitehead Institute in 1981 (and will hold the rights to all patents growing out of this research); Harvard received $23

Although the federal government in the 1980s began to encourage patenting of university technological research, its policy with respect to fundamental research remained unchanged. See Pamela Samuelson, "Innovation and Competition: Conflicts over Intellectual Property Rights in New Technologies," **Science, Technology, & Human Values** 12 (Winter 1987): 13.

Charles C. Caldart, "Industry Investment in University Research," **Science, Technology & Human Values** 8 (Spring 1983): 26.

million from Monsanto and $6 million from Du Pont for technological research; Massachusetts General Hospital received $70 million from a West German firm, Hoechst Inc.; and similar such ventures have been approved at Yale, Stanford, Washington University, and the University of California. At any rate, many universities have taken advantage of the University and Small Business Patent Act and have classified the focus of their work as technology, not science.

Whatever the answer or outcome of the above problem of intellectual property rights, it is clear that the debate would not be raging if there were not deep differences between science and technology, both in theory and in practice. And I will argue below (third chapter) that these differences between science and technology are crucial in understanding why the USSR failed to achieve a post-war revolution in technology and science which even remotely resembled the revolution in the West.

Ibid.

See Vivian Weil, "Introduction to Special Section Private Appropriation of Public Research," **Science, Technology, & Human Values** 12 (Winter 1987): 1. Since many truly innovative technologies which universities produce do not fit into any category of "scientific property," the federal government--keen to reduce its level of funding of university research--has actively encouraged the idea that university technological research is an important source of revenue. The government notes that patenting such technology does not inhibit the free-flow of such information, since the patent is, by nature, a complete description of the product or process.