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CHOOSING THE FUTURE SCIENCE, TECHNOLOGY AND PUBLIC POLICY

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Abstract

The relationship between science and technology and public policy is pervasive. Almost all public policy issues are affected by science and technology to some extent, sometimes in a minor way, but often critically. But, even when they are central to an issue, they are not on their own determinate of the policy outcome. Rather, the policy choices are always an interaction of many variables in addition to the scientific and technological elements. A brief historical summary will trace the rise of both science and technology in the West, their interaction with each other, and their growing significance in the economies, armies and status of nations. Among the more striking developments, especially since World War II, are the startling and often massive changes in many of those subjects that are determinate in the relations among nations: weapons, economic strength, trade, energy, communications, transport, food, population, disease, to name only the most obvious. A common characteristic of these changes is the degree to which they lead to or require international interaction and cooperation. But what is quite surprising is that the international system of nation-states has not been massively altered in response. The level of interaction among nations has certainly grown, but the basic structure of nation-states, each jealous of its independence and its freedom of action has continued. As we look to the future, can/will this still be the norm? Will some of the changes, particularly in nuclear weapons and now what we call globalization, furthered by continuing advances in science and technology, bring about more fundamental evolution in international politics? Though there can not be a definitive answer to this question in advance, we will make some observations using recent history and relevant policy issues as guides.

Biodata

Eugene B. Skolnikoff is Professor of Political Science at Massachusetts Institute of Technology, (MIT), USA. He has focused his research and teaching interests in the field of international affairs, with a strong emphasis on the political changes brought about by rapid scientific and technological change. From 1970-74 he was Head of the Political Science Department and from 1972-87, Director of the Center for International Studies at MIT. Prof. Skolnikoff has worked on the White House Staff in the office of the Science Adviser in the Administrations of Eisenhower, Kennedy and Carter, dealing there and in his activities at MIT on issues including nuclear energy and weapons, proliferation, foreign aid, space, foreign policy, global warming, information technologies, and international organizations. He has also taught at Yale and the Fletcher School at Tufts. He was co-director of a research project on international environmental agreements at the International Institute for Applied Systems Analysis in Austria from 1993-7 and has been a consultant to a number of U.S. Government agencies, including the Departments of State, Energy and Defense, and the National Science Foundation and Congress' Office of Technology Assessment, as well as to international organizations, private foundations, and industry. Prof. Skolnikoff is currently on the National Research Council Committee on Science, Technology, and Health Aspects of the Foreign Policy Agenda of the U.S., a committee set up at the request of the Department of State, and is a member of the NRC Space Studies Board where he serves as Chair of the Committee on International Space Programs. Prof. Skolnikoff has published numerous articles and several books, including *The Elusive Transformation: Science., Technology, and the Evolution of International Politics* (Princeton University Press, 1993) and, with David Victor and Kal Raustiala, *The Implementation and Effectiveness of International Environmental Commitments: Theory and Practice* (MIT Press, 1998).

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The relationship between public policy and science and technology is pervasive. There are no issues that do not involve science and technology in some way, to some extent. At times, the scientific and technological aspects are critical elements of an issue, central to its understanding and resolution, for example, modern weapon systems or environmental risk assessment. At other times, the scientific and technological aspects are minor, even when they may have been the trigger to create the issue or move it higher on the agenda, e.g. agricultural trade, spread of disease, or economics of health care. In either case, the scientific and technological aspects do not determine policy outcomes or choices.

Public policy issues are always a matter of interaction among many variables: political, social, economic, psychological as well as scientific and technological. Not, do science or technology ever cause any policy outcome on their own. Even technologies as dramatic as the atomic bomb do not by themselves determine whether atomic weapons will be used or not.

Scientific developments and their applications in technology, or technological developments of themselves, may alter relevant factors of an issue; determine who are the significant actors; change the framework of the issue; and modify perceived costs and benefits.

Editor's Note: Professor Skolnikoff was in Malaysia on the Fullbright-Hays Senior Fellowship and served as Visiting Professor at the Institute of Malaysian and International Studies (IKMAS), UKM for two weeks from the end of February to early March 2004. On March 2, he delivered a public lecture organised by IKMAS at Universiti Kebangsaan Malaysia on the topic "Science, Technology and Public Policy: Choosing the Future". The lecture as well as the Q&A was transcribed and subsequently edited by Professor Skolnikoff for publication in the IKMAS Working Paper Series.

But, the policy outcomes come about through actors in a political/economic system, through the choices they make, and through the cumulative responses of society and its institutions, not because of the existence of scientific knowledge or of new technological capabilities. These are elements to be included; they may even be "forcing" factors that lead to pressure for a societal response. But they remain only an element of an issue, to be considered along with the political, economic and social factors. How did we arrive in today's "technological age?" Let me present a brief historical summary, touching on a few of the most significant milestones.

The scientific age can be said to have begun in the seventeenth century with Francis Bacon's recognition of the significance of a disciplined method for development, testing and verification of theory; in short, for experimentation with standardized measurements. His concept became the essential foundation for all that followed by recognizing the cumulative nature of science that transcended the capability of individual scientists. The British Royal Society propagated the Baconian doctrine, providing the base for the development of a scientific community that steadily expanded as succeeding generations built on what went before. It was that adoption of the scientific method that distinguished science in the West from science in Islam or China, both of which in the fifteenth and sixteenth centuries could be considered to have scientific and technological accomplishments well in advance of those of Europe.

The success of the new scientific ideas was aided by the gradual loss of authority of the church in Rome and by the breakdown of feudalism, allowing controversial ideas to be heard and promulgated. This is still a valid observation today as we see the effects on science of fundamentalist religion and of highly authoritarian family structures.

The achievements of the scientific community in the West over succeeding centuries amply demonstrated the value of this approach to the study of natural phenomena. Strongly aided by technological developments such as the printing press, the telescope, the microscope, accurate clocks, and countless others, science and scientific research became a major intellectual activity throughout Europe, spreading in time to the New World, as well as to the nations of the East. Those technological developments, so essential for science and for the economic growth of the West, however, were themselves not the products of research. They preceded scientific understanding and typically were developed without knowing how or why they worked; many, in fact, provided the impetus for development of new scientific fields. It took almost 300 years before science became an important factor in commerce or war, that is, before the results of the laboratory became the basis for substantial practical innovations. Instead, technology advanced in those years in a close relationship to economic growth. Which was cause and which effect--economic growth or technological innovation-- is not critical; the important observation is that the two went hand-in-hand over much of Western history since the late middle ages. There is good reason to believe, however, that economic growth today is now clearly dependent on successful technological innovation.

The environment that made economic and technological growth possible had many and varied components. Rosenberg & Birdzell[1] single out three closely intertwined elements as critical: the growth of autonomy, diversity, and experiment. Autonomy is a result of the weakening of political and religious controls, allowing individuals and organizations to challenge existing patterns of power and structure, to experiment, to take risks. Diversity grew out of the effects of autonomy, as institutions able to cater to differing resources and to differentiated needs came into existence. Experiment was an essential aspect of the other two, for it admitted the possibility of change, change in organizations and change in technology, and carried the implication of both the rewards of success and the risks of failure.

By the end of the nineteenth century, the role of science became more closely tied to application, whether for wealth or for war. Industrial research laboratories began to appear in the last quarter of the century, particularly in chemistry. They were established as it became necessary for commercial exploitation to understand why things worked as they did, and in part as the subject matter of technology--electricity, magnetism, chemical processes--required specialized knowledge and experiment not

[1]Nathan Rosenberg and L.E. Birdzell, Jr. 1986 *How the West Grew Rich: The Economic Transformation of the Industrial World,* New York: Basic Books.

accessible even to the experienced artisan without benefit of more systematic technical training.

Gradually, and then more rapidly in the twentieth century, this introduction of structured research and experimentation in industry in the interest of innovation, at the time unique to the West, became a self-sustaining system. Judged by its results, it was one of the more important institutional developments of that century, serving to accelerate the rate of change of technology and thus of change in society. In the words of Rosenberg and Birdzell: "it improved recognition of the possibilities of change, reduced the risks of attempting change, and increased the probable rewards of change. It thus altered the goals and incentives of Western economic systems toward more change and growth."

The other key institutional development of the twentieth century that provided enormous stimulus to technological innovation was the growth of the role of governments in support of both science and technology, at first primarily for security purposes. This was not a new role, for states had long been interested in technological innovation for application to armaments and the waging of war, but predominantly as a potential customer of independent developments rather than as paymaster to develop technology. Even then, governments were not always willing consumers when new technologies threatened existing military organizations or tactics. Steam power was long delayed in being applied to navies in the 19th century because of resistance from senior officers, as was the adoption of the bomber early in the 20th by the U.S. Army, or even the ballistic missile by the bomber-equipped air force in more recent years.

But, later in the 20th century, at first modestly and then with savage intensity during World War II and the years that followed, governments have devoted huge sums to the support of science and technology for military applications. The interwar years saw substantial advance in the knowledge that could be applied to weapons in fields such as aircraft, radar, mines, tanks and the materials and electronics that backed them up. When the war came, the commitment that was then made to the scientific and technological enterprise for war purposes on both sides had no earlier parallel. The developments in nuclear energy, radar, proximity fuses, V-2 rockets, bombers, bombs and bombsights, communications, intelligence, materials, organization, operations research, and countless other fields, all supported with government funding, usually in new or wholly transformed organizational forms and units, and involving thousands of scientists and engineers who had no previous knowledge of the requirements of warfare, was entirely unique, and quite spectacular. It is a fair judgment that this was the first war in history in which the scientific and technological developments made during the war had an effect on the outcome of the war. They may even have been the major factor in determining that outcome.

It was not only in the furtherance of military goals that governments moved increasingly toward direct support of science and technology. There had been a long tradition of commitment of funds from public treasuries for scientific activities that would redound to the greater glory of the nation or the king, or might have more pecuniary or other useful results. The Age of Exploration saw many expeditions launched to advance knowledge, along with claims of territory and hoped-for discovery of new sources of wealth. Individual scientists in Britain, France and Germany in the 17th, 18th,and 19th centuries often were provided with necessary funds by patrons, some of whom were monarchs, government officials or ministries, frequently acting with quite mixed motives. President Thomas Jefferson engaged the young United States of America in the support of the Lewis and Clark expedition to explore, record flora and fauna, and map the Northwest of the continent. The purpose was seen as an investment for the future commerce of the nation and incidentally to establish a territorial claim; science was in effect the vehicle to accomplish those practical aims. Almost a century later, the United States embarked on a seminal commitment for the support of agriculture research (and transfer of knowledge to its use on the farm), that provided the knowledge and experimental base over the next 100 years that made agriculture in the U.S. the most productive in the world.

Until the late nineteenth century, this support tended to be erratic and sometimes capricious. Important as it was in furthering the growth of science and the scientific community, only gradually in the 20th century did some governments begin to assume more direct responsibility for the general support of science and technology. Attention was at first heavily weighted to fields of obvious social interest, such as agriculture and medicine, but then became more eclectic, especially as the extraordinarily exciting work in nuclear physics expanded in the 1920's and 30's. It was primarily European governments that provided support for science; in the U.S., the prevailing practice of providing government funding only for well-defined practical objectives, due in part to perceived constitutional barriers, deterred substantial public funding of what would now be called basic research. Much of such research was in fact carried out either with support from private foundations--a major factor in the development of science in the U.S. in the interwar years–or with public funds under the rubric of suitably "public" goals such as naval navigation, weather forecasting, aircraft design, or geological surveys. Though the center of gravity of science remained in Europe in the early decades of the century, basic research developed rapidly in the U.S. after the 1930s, especially in the universities, measurably helped by the influx of refugee scientists Hitler drove from Germany.

Any lingering question about the relevance of science and technology to national purposes was erased by the experience of the Second World War. Not only was the importance of public investment in science and technology in the security field now clear, but the potential benefits in other areas of social interest also appeared to be obvious. The spectacular applications of the theoretical studies of the atom demonstrated vividly that even basic research could be directly relevant to the achievement of national purposes. Governments, particularly of the former combatants, took up the support of research and development as a clear national commitment; with the onset of the cold war, this commitment grew to become a substantial fraction of government expenditures, for most industrialized countries larger than the R&D expenditures of the private sector during many years after the war.

There are many variations among nations in the details of those commitments: the United States, for example, to this day has limited government support for the development of technology in commercially-oriented subjects outside agriculture and health. And, some nations rely much more heavily on defense-oriented research and development (R&D) expenditures than do others; in 1988 the U.S. devoted approximately 65% of the federal R&D budget to defense, while Japan allocated only 5% for that purpose. The absolute size of overall support varies widely, as might be expected, roughly paralleling differences in GNP. Proportionally, however, most of the larger Western nations, including Japan as "Western," spend between 2-3% of their GNP on R&D.

The U.S. emerged in the postwar era as the dominant scientific and technological power, but by the end of the1980s the overall picture was in the process of change. The scientific and technological competence of many industrial nations had grown to challenge U.S. dominance, though the U.S. clearly remains the leading scientific and technological nation across the board. Moreover, the end of the cold war implied a decreasing role for the military and for security goals in the support of R&D. Economic competitiveness became an increasingly important issue, with the role of science and technology seen as a key factor in determining a nation's international economic position. At the same time, considerable uncertainty prevailed about the appropriate and effective policies of government in the stimulation of technological innovation. Today, after Sept. 11, 2001 there has been a partial return, at least in the U.S., to a focus on the military, anti-terrorist applications of R&D.

Thus, institutional changes in the 20th century and particularly since the Second War, have transformed the scale of the scientific and technological enterprises, and the relationship of those enterprises to a nation's economy, to its government, and both of those to the rest of the world. By today, 2004, the combination of industrial and governmental support for R&D totals globally somewhere in the vicinity of $750 billion per year, with the U.S. accounting for roughly half. Much else has changed, of course, in the role of government itself in relation to social and economic issues, in the general wealth of a privileged portion of the world's population, in the very size of the world's population, and in the nature of the relations among nations. Applications of the results of science and technology that have emerged from these transformed enterprises have had much to do with those larger societal changes just as those larger changes, in turn, have had much to do with the development of the enterprises.

The implications of these developments, especially in the last half century, clearly affect all of us in major ways. I want to focus here primarily on the interaction with international affairs, with the evolution of the international political system as it has been affected by science and technology.

It has become commonplace to observe how much the startling pace of change in world affairs that characterizes the last two centuries and especially the years after World War II owes much of its dynamic to science and technology-related developments that have had global consequences: the deployment of massive strategic nuclear forces, computerized financial markets that allow currency transactions estimated at more than $1 trillion per day, the eradication of smallpox, or information technologies epitomized by the Internet, or the spread of dangerous technologies capable of being misused. Other developments may be less immediately spectacular, but as far-reaching: the ability to fax documents and to reach any telephone instantaneously and inexpensively on a worldwide basis, the increasing dependence of modern weapons systems on technology and on technological advance, the relevance of technological innovation to a nation's competitive position, and the immediacy and global reach of television. Still others serve to underline the more intensive relation between local actions and global consequences, such as destruction of stratospheric ozone due to the widespread use of chlorofluorocarbons (CFCs), the far-reaching consequences of a disruption in energy supplies, or the climatic effects of the accumulation in the atmosphere of the waste gases of energy-based economies.[2]

The international significance of science and technology is not only a result of recent advances, though the breadth of interaction and the rapidity of technological change are relatively modern phenomena. Historical examples are countless, ranging from new weapons technologies that altered the fate of nations to industrial technologies that were the basis of revolutions in economy and wealth. It was not only the physical developments of technology that had an impact; the intellectual currents of the Enlightenment, so much a product of the ideas of experiment and rationality of the scientific revolution, served to stimulate massive forces for change in the West. Even the design of government in the American Constitution was in part a product of those forces. But it is the changes of the last century, and particularly the post World War II years that are the most startling.

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[2]The implications of these and other developments for the international political system are analyzed in detail in Eugene B. Skolnikoff, 1993. *The Elusive Transformation: Science, Technology and the Evolution of International Politics*, A Council on Foreign Relations book, Princeton, N.J., Princeton University Press.

It is even more startling when we realize that we make these observations of the effects of science and technology based on changes that have occurred over an astonishingly small slice of world history. Consider: the structure of DNA was first understood in 1953, just over 50 years ago, and the genome itself mapped only in the past two years; the key experiment demonstrating atomic fission was carried out only 66 years ago and the first atomic bomb exploded 7 years after that; the dominant innovations in the development of computers and TV date back about 70 years; the video tape recorder (VCR) was introduced only 48 years ago (I know because I took delivery and conducted proof tests on the very first in 1956); the transistor was invented during the same time period; heavier-than-air flying machines date from about 100 years ago, and even the telephone and automobile are only about 130 years old.

But, recorded human history extends back perhaps some 8,000 years. Our species has been around for more than 100,000 years; and it is 65 million years since the demise of the dinosaurs provided an ecological niche that allowed the evolution of mammals, to say nothing of the 5 billion years of the planet and the emergence of life probably some 4 billion years ago. It may well be a rather quixotic exercise to describe with confidence the effects of scientific and technological change on any contemporary aspect of human affairs.

Moreover, science and technology are not static. As I said, something in the vicinity of $750 billion per year, probably more, is invested in the support of R&D worldwide, leading inevitably to rates of innovation that defy accurate forecasting, let alone of their social effects. Prediction of scientific advance is always hazardous at best. Nature still has the capacity to surprise and astonish us; predictions based on today's science and technology are bound to be suspect. We can be sure, for example, that the rapidly unfolding developments in molecular biology occurring today, and there is much more ahead of us than behind, will blossom in ways that simply cannot be foreseen.

Today, given the scale and organization of the scientific and technological enterprises, science and technology have become arguably the most powerful and persistent factors leading to societal change and, necessarily, to change in international affairs. There is now in place a formidable, and growing, capacity a system for targeting human ingenuity toward the rapid expansion of knowledge, and for the production of new technologies designed to serve perceived or speculative needs. Not only do the results of this system have significant international effects, but its very operation favors the creation of global markets or a global setting for its products.

As an aside, it is a fascinating, perhaps disturbing, but unanswerable question as to where we are on the S-curve of change common to all technologies: in the middle where the slope is most rapid, nearing the upper bound, or perhaps still in the early phases. Wherever we are, and we will only know in retrospect, that must raise questions about the sweeping generalizations often made, and also must cloud judgments about a future that will inevitably be substantially different than today.

We are, in other words in an environment of sustained change; the one constant, paradoxically, is change.

The implications for the international system can be summed up in a cliché: that advances in science and technology and their application have led to an unprecedented degree of interaction and mutual dependence among nations in their economies, social structures and security relationships. The result has been to move nations and industry to new levels of interdependence that has come to be called, critically among some, globalization. Even if a cliché, it is undoubtedly correct. In fact, this interaction is continuing, likely accelerating, along with continued advances in science and technology.

But I would also argue that the fundamental principles and organization of the international system have not been substantially altered. The nation-state, despite much rhetoric to the contrary, is still with us and will remain so for the foreseeable future. And, in my view, the nation-state structure, with all its problems, will be essential to manage this increasingly complex and interdependent world so much altered by the capabilities placed in our hands through science and technology.

In other words, notwithstanding the astonishing changes in weapons, in economies, in communications, in trade, in energy, in health, in the environment, we still are part of a system that retains the basic structure of independent states, each (to varying degrees) jealous of its independence, each seeing itself in competition with others, each attempting to maintain as much freedom of action as it can, and each committed to maximizing national welfare and influence.

These characteristics of the system may be eroding somewhat due to the degree to which states have become dependent on others, but in my view nowhere near as significantly as rhetoric often claims. Even the European Union (EU), at present still an international organization, though a powerful one with respect to its members, has major hurdles ahead if it is to succeed in overcoming its underlying national structure. I have serious doubts that it will. But if the EU does succeed, it will become simply another state.

It is worth recognizing that R&D supported by governments, and much of that supported by industry, is largely still allocated, including in Europe, in a nationally-based process, determined by goals defined dominantly in a national context, conditioned by national resources and manpower, and subject to the constraints of national economic, budgetary and political processes.

I believe these two phenomena a persistent nation-based international political system and interdependence or globalization are not necessarily contradictory. It is theoretically possible that a different history might have unfolded, with substantial diminution of the power of the nation-state in favor of international organizations (as was widely expected at the end of World War II). But it hasn't happened, for quite explainable political reasons. Rather, governments have had to learn to accommodate to new limits on their freedom of action, to cooperate more extensively with others to achieve national purposes, to build an international structure of organizations to cope with frontiėr-spanning problems, and to accept that their policies must reflect greatly increased international interaction in almost every sphere of life. They may have difficulty managing successfully in this more complex world, but governments remain the focal point for a nation's ability to navigate in that world and will continue to be so.

But these judgments are generalizations. In practice, how do the policy processes of nations deal with issues with significant international consequences for which the scientific and technological aspects are clearly central, might be thought to be the dominant considerations, and might have been expected to overturn traditional patterns in the international political system?

Let us look at two of these science and technology-rich issues high on the political agenda today: climate change and, as time permits, natural resources, especially those required for the production of energy. These two and the many others that could be cited, weapons of mass destruction, proliferation, mad cow disease, GMOs, or the spread of contagious disease such as SARS and AIDS, though all quite different, have several elements in common. One is that the scientific and technological knowledge surrounding them is, to varying degrees, and necessarily, uncertain. Second is that they touch on important values in a nation, be they economic, security, political, cultural, religious, or ideological. Third is that the media has a major effect on how information reaches the public on these issues and thus, how the media presents the various elements, including particularly the scientific and technological elements, is crucial to forming public views. And finally, to reflect the effect of these elements on my own country, the United States, where the structure and policy process of government make it harder to reach policy closure on issues with major implications and substantial levels of scientific uncertainty than it is for any other industrial democracy.

To start with climate change: for our purpose, a detailed review of the whole climate change history is not necessary; the present state of play can be quickly summarized. The Intergovernmental Panel on Climate Change (IPCC), a panel of scientists commissioned by UN agencies with scientists drawn from all over the world released its third assessment report in 2001 (it is now working on the fourth). The "Summary for Policymakers" stated that in the Panel's judgment it is now clear that the global climate is being affected by the actions of mankind, mainly the effluents of human societies, and they predicted that the temperature rise by the end of the century would be in the range of 1.4 to 5.8 degrees C over the 1990 level. That doesn't sound like much, but the report notes that "The projected rate of warming...is very likely to be without precedent during the last 10,000 years..." Various consequences, most of them harmful, for changes in precipitation, sea level, and reduction of snow and ice cover are forecast with varying degrees of confidence in the forecasts.

Though provided by a large panel of scientists, the forecasts have been challenged by some, particularly in the U.S., who argue that the warming, if it is occurring, is just as likely to be the product of natural variations in climate and that the magnitude of any warming is likely to be smaller and over a longer period of time than the IPCC conclusions. These so-called "skeptics" constitute a tiny band of individuals, but their views are magnified in the press and the nature of this complex science means their claims cannot be actually disproved.

Earlier forecasts of prospects for global warming led to the Framework Convention on Climate Change negotiated at the Earth Summit in Rio in 1992 that was signed and ratified by more than 186 countries (the US, under President Bush Sr., was the first industrial country to ratify.) The Kyoto Protocol, negotiated in 1997, was intended as the next step to carry out the general injunctions of the Framework Convention. The Protocol mandated specific reductions of greenhouse gas emissions from the arbitrary base year of 1990 by industrial countries by 2008-2012, with the U.S. accepting a target of 7% and the EU 8%. Developing countries were not asked to make any commitments at this time.

The U.S. signed the Kyoto Protocol under President Clinton but Clinton did not submit the treaty to the Senate for ratification (it would have been rejected at that time). The current President Bush summarily denounced the Kyoto Protocol in 2001, arguing that it would have unacceptable costs to the U.S. economy. As a result of economic growth since 1990, the U.S. would have to cut emissions by some 30% or more by the end of this decade, a target that is by now clearly not politically feasible. He also argued that the developing countries that would be the largest producers of greenhouse gases in a few years would have made no commitment to curb their emissions.

What is behind the unwillingness of the U.S. to respond to the scientific forecasts and to make the policy changes that would be required to meet a commitment President Clinton signed? How much of a role does science play in the U.S. and elsewhere on this issue?

Climate change is one of a small number of issues that are high on the policy agenda entirely because of science and scientists. At the time of the 1992 agreement at Rio there was no solid evidence of any warming, let alone actual damage. The concern that propelled the issue on the agenda was solely based on the forecasts of scientists, supported not by evidence of warming but by the buildup of CO_2 in the atmosphere as measured on a mountaintop in Hawaii and by the forecasts of computer models of the implications of such a CO_2 buildup. Those forecasts appeared to be validated by the string of hot summers of the 1980s that lent political and media support to the emergence of the issue. The successful ozone layer negotiations that followed a seemingly similar negotiating path also contributed. These latter led to the Montreal Protocol that has brought about a reduction of 90% in the production of ozone-destructive CFCs. As a result, it was thought to be a model for dealing with greenhouse gases, but in practice has proven to be a poor precedent for the much more complex and controversial issues associated with global warming.

Science, even with large uncertainties and many often controversial forecasts, was the dominant factor in the emergence of the issue. But, when one examines what is now driving the policy process quite other factors prove to be crucial.

In the U.S., the uncertainties inherent in the scientific forecasts give free rein to the political and economic interests that would be affected. Though there is greater public acceptance of the reality of global warming, there remains considerable uncertainty about the scale and timing of any warming that might take place and of the most reasonable way to respond. It is a staple of all public policy processes to have to cope with uncertainty; scientific uncertainty is simply a special case. Uncertainty allows those who oppose action to question the legitimacy of forecast risks, and to argue that costly actions are unnecessary in case the risks are overestimated. It also leaves the door open to alternative scientific analyses (in fact, it stimulates such analyses) by those who perceive that their interests are threatened, thus increasing the perception that the science is uncertain.

In the case of climate change, moreover, the uncertainty is not limited to the evidence on warming. There are even larger questions about the ecological, physical, and economic consequences of a significant change in climate. Equally contentious, the costs of the measures to mitigate warming or to adapt to it are also dependent on a variety of assumptions, for example about likely evolution of technology, anticipated economic growth, the sequencing of specific policies, and the actions of other nations.

These many uncertainties lead to a critical role in the policy process not for science but for the asserted economic and political implications of warming and of the costs of measures that might be taken to prevent it. These implications cannot ultimately be evaluated independently of the science, but in the immediate policy process factors other than science dominate.

The many questions surrounding the economic consequences have a reverberant sounding board in the American political structure. With a fundamental division of power between the Executive and Legislative branches and an adversarial approach to resolving policy differences, the U.S. government necessarily finds itself in internal conflict over any issue that touches major interests and ideologies. To compound matters, almost every agency in the Executive branch has some legitimate interest in the climate issue, while most Congressional committees are (or will be) involved in the debate, each with turf to defend or expand and each with a limited vision of the national interest. Moreover, as a result of the organization of the Congress and its relative independence from the Executive, interest groups have easy access to the levers of power.

In this setting, the role of scientific evidence is not the overriding factor in this most "scientific" of issues, and must take a back seat to the political, economic, and other factors involved. Science may indeed become the principal argument that all sides use to justify positions reached primarily on other grounds. The policy problem is magnified when the issue has high visibility and the economic stakes are large, as is the case with climate change. Those who stand to lose from efforts to reduce emissions find it more acceptable to question the science than to defend their interests directly. Challenging the science is also effective because most of the public cannot judge the attacks and thus can be easily misled or confused. As a result, disagreements among scientists are amplified and the science itself appears more uncertain—to both the public and Congress—than would be the case with a less prominent issue or one with fewer consequences.

Adding substantially to the difficulties in the process is the fact that the benefits of present expenditures will not be realized until far in the future. Politicians do not like to be in the position of advocating costly and often unpopular policies whose benefits are entirely over the horizon while there are more immediate needs to be addressed, especially when the case for such expenditures can be challenged as "not proven." Especially is this so since we will surely be richer in the future than today. A growth rate of, say, 2% means the economy will double in approximately 35 years; 4% means doubling in about 15-20 years.

To these factors can be added several others. For example, one policy option to reduce emissions could be an energy or carbon tax to encourage conservation and the development of alternative energy technologies. Given current political attitudes in the U.S. toward new taxes, a carbon tax of any meaningful size is not a likely development in this, or any, administration.

Another relevant attitude on the part of some in the U.S. is antipathy to international organizations. Particularly manifest in the Senate, it has meant deep skepticism on the part of some in that body about the role and effectiveness of the UN and other international bodies. Since the negotiations about climate change have been conducted from the start in multilateral forums, any long-term resolution will inevitably involve international organizations as key players.

Finally in the U.S., partisan politics is of more than passing importance. Partly because of Vice-President Gore's commitment to the issue, the Republicans have tended to see this as a Democratic issue. President Bush made a few skeptical references to it in the campaign, even though it was his father who committed the country to the Framework Convention at Rio. But he did indicate that he would add CO_2 to the list of pollutants that would then be appropriate for regulation under the clean air act, a commitment that he withdrew after his election. However, the measures that would be necessary to come to grips with the issue appear to be those that are more typically associated with Democratic administrations – taxes, regulations, and international commitments. In fact, however, the Clinton administration was a strong proponent of market-based mechanisms for finding lowest-cost means for reducing emissions. That has not altered the perception of the partisan nature of the subject.

That is roughly the parameters of the current debate in the U.S., though of course there are many additional aspects and details. Note, however, how the policy debate engages, in fact is dominated by, many elements other than the scientific evidence of global climate change. Rather, other factors that are largely domestic in nature dominate. In my view that would continue to be so even if the uncertainties in the science were greatly reduced.

The debate could be transformed rather quickly in several ways. One would be dramatic climate events that could be responsibly and plausibly tied to climate change. Disappearance of the snow atop Mt. Kilimanjaro and the retreat of glaciers worldwide may qualify, or at least contribute. Media treatment of the subject has already played an important role in placing the subject on the agenda and would do so again if events occurred that could not be explained as normal variations.

It would be good to be able to argue that new scientific evidence would turn the debate in the US. Perhaps. But I confess I very much doubt that scientific forecasts alone will be enough to trigger policy change on this high-stakes issue.

I should briefly make it clear where I stand on this, to avoid a possible impression that I do not take the danger seriously. Quite the contrary, I believe the issue is very serious, though it is a century-long problem, not something that is amenable to short-term deadlines. In my view it was a bad mistake to set emissions reduction targets for the end of the first decade of the century, especially not in a forum of 180+ countries, for we neither knew enough, nor had the technology or international machinery in place to take action, nor would there be any real prospect of meeting the targets from a political perspective. The Kyoto history was not a waste of time, for many not very visible steps have been taken. But now we have to figure out how to move ahead without abandoning Kyoto fully, perhaps with unilateral national measures constraining emissions to a meaningful but limited extent over the next decade, a much greater commitment to R&D on energy efficiency and alternative technologies, and a mix of bilateral as well as multilateral agreements that can then be discussed in the larger Kyoto setting. Whatever we do, the scientific forecasts are critical, as are the development of technological options, but they are only part of the issue. I wish that I could report that the current U.S. administration agrees with this view. It is supporting R&D, but avoiding any real commitment or negotiation.

Let me more briefly discuss the other topic I mentioned, natural resources, with emphasis on fossil fuels. The continued availability of natural resources is a subject that has bedeviled international relations throughout history. It has been a source of friction and sometimes warfare among nations. At least from Malthus in 1826 up to and including today, there have been repeated predictions of resource scarcity and catastrophe. In fact, however, commodity prices today are generally lower than they were a century ago.

Forecasts of depletion of oil follow that pattern. In 1850, almost 90% of energy was from biomass–wood. From 1850 to 1950, energy use was up by a factor of 4.3, largely from coal. In the next half century, to 2000, energy use was up almost five times, predominantly from oil and now also natural gas. Note that it takes about 40-50 years to move from one energy system to another. Today, fossil fuels account for almost 80% of energy production, biomass, hydro and nuclear the rest.

But even given this much greater use of oil, prices of gasoline have risen only modestly, even in the current runup of price that is due largely to political restrictions on the part of OPEC. Net of taxes, the cost of gas today in inflation-adjusted dollars is actually lower than it was during the oil shocks of the late 1970s.

Economists argue, quite appropriately, that when resources are scarce, their price should rise unless artificially constrained. But oil prices have not risen, except when constraints were put in place by OPEC. Either there is plenty of oil, or the market has not internalized the actual scarcity of oil in the price. Repeatedly, predictions of future oil production and price have been, quite simply, wrong. Typically, it is forecast that there will be a production peak in the next, say, 10 years and then an inevitable decline. 10 years later there is a similar forecast about the next 10 years. On a global basis, it has not risen except when political decisions have limited production.

Why are the predictions so far off? Some of the reasons are simple errors:

- identified reserves are not the same as total recoverable oil
- the assumption is often made that most oil has already been found
- it is not unusual for political/economic bias to affect the predictions
- sources that are presently high cost (shale, oil tars) are not counted (Canada is already marketing its huge shale and tar sand reserves)

But some of the explanation goes to the causes of misreading of natural resource availability in general, in particular giving inadequate weight to technological change:

- to the development of substitutes
- to greater efficiency of use
- to improved ability to find and recover resources such as oil.

If the price did rise because of scarcity or by policy decision, technological change would come more quickly for the rewards would be realized that much faster.

Oil and natural gas are clearly essential for all industrial and developing economies, for economic growth and for security. That dependence has for long made them prominent and contentious geopolitical commodities. It is not only that nations need them so fundamentally, but that the infrastructure of their use in an economy cannot be altered quickly as noted, it is on the order of 40-50 years to completely revamp energy systems from one fuel to another--thus making the dependence longer-lasting and not subject to quick correction. The additional snag, of course, whether oil is in short supply or not, is where it is found. Those two factors– location and time to effect change in dependence are what make oil such a geopolitical commodity.

Hence the political furor over the Middle East, the conflicting claims over the Spratly Island, the competition to find oil resources wherever they can be found, and the pressure to build secure pipelines. Essentially the same observations apply to natural gas, but much less so for coal, for which known reserves are adequate for centuries, of course with serious environmental side effects.

Eventually the world will have to evolve to a non-carbon economy, but that will be a slow process. It is actually moving in the right direction (though the much-touted hydrogen economy will be far off) for the carbon intensity in the production and use of energy is decreasing, and has been for a number of years in all countries.

Other non-renewable resources demonstrate the same pattern as fossil fuels, though without the dramatic geopolitical consequences. As with oil, numerous predictions over the years have forecast depletion, crises and inevitable resource wars. But scarcity occurs only in localized situations while overall prices fall through substitution, improved discovery and recovery, and greater efficiency of use.

Will these observations always be true? Will technology and resource substitution always rescue us? Will we never run out of resources? To put it another way, is the Earth finite? Is there a limit on non-renewable natural resources?

Obviously the earth is finite in a symbolically important sense of one planet, one global village. But, with regard to natural resources, no, it is not finite. We will in principle always be able to find ways around resource limitations. As scarcity emerges, it will cause prices to rise, which in turn will stimulate greater efficiency of use and development of alternatives. There may be temporary dislocations, but they need never be permanent. Unfortunately, that does not mean we will always respond as we should, that we will anticipate in time the need for seeking alternatives through R&D investment. Thus, it is up to the wisdom of our policies whether we can and will take the measures to avoid the vulnerabilities inherent in dependence on natural resources.

In fact, contrary to usual assumptions, it is renewable resources --water, air, environment-- that are the real scarce resources. They are the ones at greatest risk, the ones we may truly find in shortest supply. Whether we can protect them will depend on political and economic policies and actions that reflect scarcity and degradation; the same rules apply as for non-renewables. It can be done, but it will be harder than for non-renewables because more deeply political and, ultimately, it will be a matter of human will and decision.

Perhaps these policy examples are sufficient to make my fundamental point: science and technology may be "today the most powerful and persistent factors leading to societal change and, necessarily, to change in international affairs," but their role in the nation-state system and in policy issues is a dense mosaic of interaction with all the other elements that go into the determination of the policies of nations and the fate of nations. Often, perhaps too often, they are relegated inappropriately to a subordinate role, but they are also rarely the dominant element except, perhaps, in the original emergence of issues on the agenda. That initiating role may happen more frequently as the world moves into an era in which global technologies and systems become more prevalent. Biodiversity, infectious disease, vulnerabilities of large essential technological systems, and others not yet identified will quite certainly appear on the international agenda.

I am not saying that governments are necessarily doing well in this new situation. In fact, it is not an unreasonable observation that the mature countries of the industrialized world are often finding it extremely difficult to deal adequately with the international challenges we all face. And certainly it is true that the nation-state system does not match the scale or structure of the new problems we face.

But the path before us is dominated by the need to improve the performance of national governments in their ability to cope with the complexities and uncertainties of the technological age. That does not minimize the importance of cooperation, nor does it minimize the increasingly important role of international organizations to deal with many, especially global, issues. But the clue to the success of those efforts will lie primarily in the strength and competence of national governments and the support of their publics. In fact, I believe for this reason that nation-states are essential to be able to meet the global challenges growing apace. Only they can mobilize the resources and the knowledge that will be required and only they can participate in and support the development and operation of the multilateral organizations that are a necessary and growing part of the international system.

I am optimistic over the long run, for even when the administration in my own country has ignored or flouted the international community in pursuit of its view of the national interest, it has had to backtrack to recognize the limits of its independence of action and to seek the help of other countries and the UN (now with the best Secretary-General it has yet had). Though advances in science and technology and our application of them have created a new world, we have to make the institutions of the old work well if we are to survive. The nation-state system we have created over four centuries will continue, for we do not have an alternative any time in the reasonable future.

Thank you.

Question and Answers

Questioner 1: Thank you very much for your very enlightening lecture on science and technology and public policy. I have four questions. Two are somewhat historical and two are, in a way, policy oriented.

In your lecture you mentioned the historical fact that when Europe began in the 17th century with many inventions, Islamic countries in general were more advanced than European countries in terms of science. Can you share with us some historical insights on why Islamic nations, Islamic civilization, didn't develop the science and technology that allowed Europe to overtake them? And did the same factors apply to China which you also mentioned?

The second one is also historical. How do you trace the trajectory of science and technology development in developing countries? Is it technology first and science second? And what kind of technology is this? From my observations, foreign technology has been imported into developing countries in a context different from theirs. If that is so, what are the implications?

My third question is future-oriented. How do you respond to Thomas Kuhn's concept of the structure of scientific revolution, of the concept of paradigm shift? If a society develops with one paradigm, what happens to that society when that has to be abandoned in favor of a new paradigm? What is the effect on science, on education?

My last point is, in a way, hypothetical but has serious implications. You have worked in the office of the science adviser of three US presidents. Now, assuming that you are science adviser in the Prime Minister's Department of Malaysia, what advice would you give to develop science and technology policy in order to advance Malaysia to achieve Vision 2020, to become a developed country? What are the ingredients of a viable policy for science and technology? Can we get good science and technology policy? In what way can we do so?

Skolnikoff: I am not a scholar of Islam, so my comments about your first question will necessarily be speculative. As I understand the difference between the West and Islam in the 17th century, it was the new ideas adopted in the West at that time that made the difference. The idea of change, of the acceptance of change, of how to bring it about through experiment and through building a body of knowledge is what emerged in the West at the time and was not, as I understand, the norm in Islam. In Islam, science was based on observation of natural phenomena; in the West it was based on observation as well, but then with experimentation that allowed new observations and discovery of new phenomena. And that led to a growing scientific community and attitude while Islam remained largely static.

Much the same was true of China, though there ruling dynasties actually made conscious decisions to abandon new technologies they were developing, superior sailing vessels being the most notorious example.

On the second question, there is no single answer, the trajectory of development varies with the local situation. One of the issues I believe to be very important, however, is whether basic science is a luxury for developing countries. I disagree fundamentally with the position that it is a luxury. If you want to train people at any level who are competitive in quality, you have to have a competent education system, and that requires capability through the entire education hierarchy. That doesn't answer the question of just what fields and how much to invest in basic research, for that will depend on the local situation, what fields are of particular interest, what natural resources exist, and so forth. And part of that equation is the training of students abroad, who can bring into the nation the ideas and skills and attitudes that are so important.

With regard to Tom Kuhn's ideas of paradigm shift, they are important in the history of science but need not affect the current training of scientists. His hypothesis is that science adopts a dominant paradigm, which then gradually frays around the edges with new information that doesn't quite fit. Eventually someone or some people come along proposing a new paradigm that better accommodates the new information. That then takes over the field. But, that is not a concern in the training of scientists, as long as they understand that ideas and theories change and develop. The critical element is that they be well-trained.

On the final point about advice to Malaysia, I would not be presumptuous and assume after two weeks here that I could give sound advice. I will reiterate, however, that I believe some support for basic science is essential and that training abroad is very important. My understanding is that overseas training has fallen off, by policy or because of the less forthcoming welcome in the US these days, which I deplore. But foreign training by itself is not enough–you must be willing to provide resources and support on the return of students or else the foreign training will mean little or, worse, will send the individuals abroad for better jobs.

There is also the area of private sector and investment from abroad. I would argue that investment by multinational companies should be accompanied by local investment in R&D. That is essential to develop ideas at home and to provide the jobs for those trained whether at home or abroad.

Lastly, a much more controversial point, is that an active and productive science must be embedded in a society that accepts change and innovation. If your cultural or religious system resists change, then I believe that is a serious problem.

Chair: For your information, we have an R&D policy, with a high percentage going for research for technological development. Only a small part goes for basic research, while in the USA, I think more than 60% of the budget is for basic research.
Skolnikoff: Of the total R&D in the U.S., the largest part by far is for development. Only 20% is for truly basic research, and much of that is expended in the universities. It is a very important part of the university system. I want to be very clear that I did not assume that your R&D support should be mostly for basic research. That would be inappropriate.

Questioner 2: I do want to make a quick comment before asking my question. You refer to Islam as though it is one universal society, when in fact it is diverse and multi-cultural, not homogeneous. The boundaries are not clear within Islam nor between Islam and the West.

My question concerns the issue of social and public policy in the sciences. I have heard a great deal about the human genome project, and also that it has been proven that there is no racial distinction between human beings. How is this knowledge functioning in the world? We may use race as a marker of organizational systems; in the US the issue of race has led to a decline of social policy, though not based necessarily on scientific knowledge. How has scientific knowledge from research directly targeted on race or from the human genome project affected social policy?

Skolnikoff: I recognize fully, of course, that there are many strands to Islam. I do not subscribe at all to Huntington's thesis about the inevitable clash of civilizations. I know him personally, but we don't argue about this.

On the question of race, there has been some research claiming that there are inherent biological differences between races that determine intelligence or other basic characteristics. No responsible scientist in the US agrees with those studies. Rather, it is clear that the differences that do exist are a product of social factors, opportunities, and family patterns rather than inherited genetic characteristics. Good social science research has shown the way to policy interventions that can make a difference–education, opportunity, economic assistance and the like–but we have a long way to go in the US on what is a major social/political issue for us.

What we are learning from the human genome is that there are genetic mutations that have been picked up by groups in the society that make them particularly susceptible to specific diseases, breast cancer among a subset of Jewish women for example. We will learn much more from the human genome, but no one believes there will prove to be major differences in characteristics such as intelligence between racial groups. Color of the skin is not a result or a determinant of genomic stereotypes.

Chair: Look at how controversies have developed in relation to the genome. Much anticipation of effects but without the basic science to understand what is real and what isn't. The effects of eating foods from genetically modified organisms (GMOs), for example.

Skolnikoff: It is easy to make the argument that we should be absolutely sure that a GMO is safe before its use. The problem is there is no such thing as absolute certainty. So it has become a big issue between Europe and the US. The Europeans follow a principle called "the precautionary principle," a common-sense idea that if there is a potential risk in the use of a new product, it shouldn't be accepted until proven safe. That sounds fine. The trouble is, what level of certainty of safety should you insist on? When you don't use a new product or process that would have advantages of cost or of reduced environmental damage or other desirable characteristics, then you are giving up those advantages; in effect, an opportunity cost. Rarely do those advocating the precautionary principle look at the other side of the equation; they look only at the risk. But we know there is no such thing as a 100% perfect technology; thus you can never prove something is 100% safe. At what point do you say the risk is low enough to go ahead because of the advantages to be gained?

There is a big difference here between Europeans and Americans, between the EU and the American government. The Europeans demand much more certain information about safety from their governments than do Americans. In Europe, the public says GMOs may be fine, but they want them labeled so they know when they're eating them. Seems logical. But that greatly increases the cost of the products, and tends to lead consumers to avoid them. The EU has taken the position that it won't import genetically modified crops, which has directly led some African

countries to reject food aid from the US in the fear that their own crops would be banned from the European market. Many have died from malnutrition in Africa as a result.
I am quite cynical about European politics, and believe that their position on GMOs is primarily protectionist in nature, a policy to prevent the importation of less-costly crops from the US.

A different demonstration of a controversy in the US related to biotechnology arises from the very close ties of the administration and the Congress to the biotechnology and pharmaceutical industries. This appears to have had a major effect on the relevant policies of this administration. One example is the new drug bill for "seniors." That bill actually makes it illegal for the administrators to negotiate with drug companies to obtain the lowest possible prices, a provision that could only come about as a result of major influence of corporations with the Congress and the administration.

One last point about the very high price of drugs in the US. The companies argue that is the only way they can finance the r/d to keep producing new medication. The argument is legitimate, but that doesn't determine what the price ought to be. And the ability of the Canadians to negotiate prices with the companies and substantially reduce the price of drugs appears to bear out the argument that the companies are charging much too much in the US market.

Questioner 3: How do science and modernism interact with traditional religious views? What is the result in the U.S.? Is secularism necessary for viable science?

Skolnikoff: You are touching on some basic issues about society and culture. I would argue that it is not secularism that is important for a scientific society, but rather the separation of religion from government. We have probably the most "religious" country right now, with more than 80% going to church regularly and a similar majority believing in God. And we have serious debates in some communities as to whether evolution should be taught at all, or only in combination with creationism, the belief in the literal truth of the bible that the Earth and all the animals were created in seven days, that Christ arose from the grave, and so forth. This is a continuing debate that will likely never be finally settled in the U.S., especially since our education system is actually run locally by communities and states, not the Federal government. Yet, somehow, this strong commitment to religion including, by the way, our current president, does not prevent a strong, innovative science and a society that accepts and welcomes change. It is a continuing struggle to prevent science to be affected by religious views that move from the social to the political, but we seem to have been able, so far, to accomplish that.

Chair: That is all the questions we have time for, which brings our session to a close. Many thanks to you, Prof. Skolnikoff.

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