Selling the Russians the Rope? Soviet Technology Policy and U.S. Export Controls

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PREFACE

This report was prepared in the course of a Rand study of Soviet science and technology entitled "Unanticipated Effects of Technology Transfer," sponsored by the Defense Advanced Research Projects Agency. The study undertakes a systematic analysis of Soviet management of technological innovation, particularly in response to the various possible effects of technology transfer.

The report emphasizes the distinction between the transfer of hardware and the transfer of expertise, and examines the relative impact of the two on Soviet industry. The principal issues are the effect of recent Soviet industrial reforms on the ability of industry to benefit from technology transfer, and the outlook for future Soviet technological advances.

The report should be of interest to specialists engaged in the assessment of Soviet technological posture, U.S. government officials concerned with U.S.-USSR technology transfer, and students of Soviet science and technology.

SUMMARY

Alarmed by the rapidly growing military strength of the Soviet Union, Americans wonder whether they are unwittingly contributing to it by transferring advanced technological skills and know-how to Soviet industry. The system of export controls in effect during the 1970s was criticized for allowing important technology to slip through to the Soviet bloc because it focused too much on products, and not enough on skills, techniques, and know-how. The most recent legislation, the Export Administration Act of 1979, mandates the development of a new review procedure that will control classes of so-called "critical" technologies rather than individual items. The foundations of American policy on export controls are now being rethought as part of a general rethinking of the premises of American policy toward the Soviet bloc.

The aim of this report is to take a new and critical look at the objectives and assumptions of U.S. high-technology export-control policy. An expanded system of export controls could be more complex, costly, and controversial than any we have had before. At the same time Americans remain ambivalent about the objectives of export controls and unclear about what such controls can achieve and what they cannot. Our thinking will be considerably clarified, however, if we bear in mind that the most important question about technology transfer in the long run is whether the receiving side is able to absorb the technology it imports, to diffuse it beyond one or two showcase locations, and to build upon it to generate further technological advances of its own. Only then does technology transfer have its most lasting consequences.

Accordingly, this report describes the main developments in Soviet technology policy over the last ten years, to analyze the reasons for Soviet technological lag and to extract their implications for export-control policy. Five Soviet experiments in the management of innovation stand out as especially significant: (1) full-cycle planning of especially important R&D projects by the State Committee on Science and Technology; (2) ministry-wide reform of the innovation system (first launched in the Ministry of Electrical Equipment); (3) increased investment in development and pilot-production facilities; (4) "one-roof" research and development corporations; (5) expansion of the role of the Academy of Sciences in development and pilot-production (especially in the Siberian Division and the Ukrainian Academy).

This array of new policies reflects a lengthy public debate in the Soviet elite (abundantly covered by the Soviet press) over the causes of weak innovation and the relative advantages of various solutions. This suggests in turn a growing realization in the Soviet Union that the traditional strategy of concentrating scarce resources on a handful of high-priority projects cannot produce rapid gains in productivity and quality for the economy as a whole, or even continue to meet the requirements of military industry.

Simultaneously, however, the Soviets have also pursued a second strategy, that of importing large amounts of Western equipment and know-how, with the aim of making rapid gains in lagging or hard-pressed sectors of the economy, such as the chemical industry. What, if any, is the relationship between these two strategies? This report makes several preliminary findings: (1) Recent Soviet managerial reforms to stimulate innovation are only distantly inspired by Western example; (2) Soviet managerial reforms and Soviet technological import programs do not appear to be directly related to one another or mutually reinforcing; (3) high-technology imports by themselves do not enable the Soviets to achieve independence in innovation; (4) however, the more highly developed the Soviets' *native* capabilities in a given branch of

technology the better able they are to profit from transferred technology to generate further advances of their own.

These findings suggest that the Soviets are failing to exploit the potential advantages of systematically *combining* Western high-technology imports and domestic reforms in the management of innovation. In certain high-priority sectors (notably military), where Soviet technological skills are already high, the Soviets' ability to learn from foreign technology is also high. Here, then, there is a clear case for export controls. But in the lagging areas in which most Soviet imports of foreign technology are concentrated, the Soviets' record in absorbing and learning from it is poor. The reasons are much the same as the ones that cause those areas to lag in the first place: They lie deep in the political and economic structure of the country, and numerous reform measures in Soviet technology policy over the last twelve years have not altered them. Neither have high-technology imports visibly improved the Soviets' ability to innovate on their own, in some instances the opposite. It is this second class of cases and the difficult matter of distinguishing it from the first that most of the American uncertainty is about.

This report argues that within the second class of cases the most effective barriers to technology transfer are those erected by the Soviets against themselves. Consequently, so long as Soviet policies for technological innovation remain as ineffective as they are now, the claimed benefits of any expansion of U.S. export controls should be examined carefully. Export controls have important if marginal political benefits, as this report will show, but they also have costs, and the task before us is to arrive at a sound balance between the two.

No one in the United States questions the need to control exports of direct military importance. To the extent that American security continues to rest on a lead in critical military technologies, then safeguarding technological lead-times is clearly in the nation's interest. Something like the present system of case-by-case evaluation, aimed at preventing clear and immediate military use of American technology by the Soviets, must and undoubtedly will continue. But the issue today is what to do about the possibility that the United States is giving away indirect military advantages through subtle channels that may call for more subtle defenses. The danger is not so much the possibility of sudden and disastrous give-aways, but rather that high-technology trade may help the Soviets to upgrade over the longer term the traditionally neglected "civilian" industries that will provide broad, infrastructural support for new weapons systems tomorrow. Does foreign technology help the Soviets to overcome those obstacles, and can an expanded system of export controls prevent them from doing so? This report's answer to the first question is, "Partially" (and we do not underestimate the seriousness of that fact); but its answer to the second question is, "Probably not."

It is worth bearing in mind that in the total volume of Western high-technology exports to the Soviet Union the United States is a small player. American high-technology exports to the Soviet Union in 1979 amounted to $183 million ($270 million to Eastern Europe as a whole), about one-tenth the level of Soviet imports of advanced machinery and equipment from West Germany, France, and Japan combined. The chances of gaining much support from other countries for an expanded system of export controls are small and growing smaller, for among the nations conducting high-technology trade with the Soviet Union one finds not only NATO allies (whose reluctance to apply stiffer export controls is of long standing), but also countries like Australia, Denmark, and Switzerland, which are unlikely to cooperate at all. Consequently we should not imagine that an expansion of export controls would be free of serious political costs; indeed, it might be unenforceable at any acceptable cost.

The issue of technology transfer to the Soviet bloc is a new instance of a very old problem: how to prevent the diffusion of valuable skills across national boundaries. History teaches that the control of technology transfer is at best a rear-guard action, achievable (and then only briefly) at the cost of regulations and secrecy that carry harmful side-effects of their own. This fact has not prevented every advanced nation from trying to impose controls at one time or another; in fact, since the beginnings of the industrial revolution, periods of relatively free exchange and transfer have been briefer than eras of control. But in the end the transfer of technology depends less on the fact that knowledge and skills have been divulged than on the fact that the receiver knew how to make creative use of them. From the loss of the secrets of porcelain manufacture by the Chinese to the loss of the secrets of the Sidewinder by the Americans, the ultimate consequences depend on the ability of the receiver to profit from them—and on the ability of the donor to generate more.

It follows that balancing the political costs and benefits of export controls requires weighing their claimed effects in delaying the Russians against their costs in straining our relations with our allies and impeding the competitiveness of our exports. Our first concern should be to remain good innovators ourselves. The case for export controls is strongest in areas in which the United States stands to make near-term military gains and in which the United States has a clear lead over other Western countries. As one moves outside this zone, toward technologies that afford the Soviets longer-term industrial gains and that are not areas of clear American superiority over the rest of the West, the benefits of export controls become more diffuse and uncertain, while the costs of trying to enforce them become progressively greater. Any widening of export controls outside the first range into the second should be undertaken only with the greatest care.

It is important to note that one issue that this report deliberately does *not* address is that of employing embargoes or other selective controls on East-West trade as political levers to influence Soviet behavior in the international arena. The issues of "leverage" or "linkage" are far larger questions, raising as they do the use of economic and technological instruments to make important political points, which can be effective as symbolic statements of American positions even if their actual technical effects are minimal. The author of this report does not necessarily quarrel with such uses of export controls; that is a question for the political process to decide. But in making such determinations it is most important to know whether export controls are effective in their *stated* aim (namely, to preserve military lead-times and the national security), to clarify what those aims imply in operational terms, and to know the costs. If this report succeeds in focusing some of the national debate around those basic technical questions, its aim will have been achieved.

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I. INTRODUCTION: A CRITICAL LOOK AT HIGH-TECHNOLOGY EXPORT CONTROLS

Is the United States putting itself in danger by failing to control more carefully the export of scientific knowledge, technology, and management know-how to the Soviet Union? Alarmed by the rapidly growing military strength of the Soviets, we wonder uncomfortably whether we have inadvertently contributed to it, through scientific exchanges, turnkey and training agreements, sales of licenses, or exports of high-technology products and processes. A decade ago, confident of our military strength and of the superiority of our civilian technology, and hopeful about the possibilities of cooperation with the Soviet Union, we began dismantling the virtual trade embargo we had maintained against Eastern Europe for nearly twenty years, and set about expanding trade and contacts. We are far from that optimism now.

On January 4, 1980, President Carter ordered a suspension of licensing for high-technology exports to the Soviet bloc pending a full review of the U.S. government's export-control policy. Although his immediate aim was to show American displeasure over the Soviet military action in Afghanistan, his action was the culmination of several years of mounting dissatisfaction in Washington with the export-control system in effect since 1969, numerous but inconclusive attempts to revise it, and severely divided opinions—all reflections, in turn, of growing American apprehension about Soviet policies and intentions.[1] Consequently, the review of export-control policy launched in the last year of the Carter administration is part of a general rethinking of the premises of American policy toward the Soviet bloc, a rethinking that has undoubtedly only begun and does not promise to be easy.

The aim of this report is to take a new and critical look at the objectives and assumptions of U.S. high-technology export-control policy. In such a difficult issue there are no simple answers; therefore it is only fair to the reader to provide a preliminary map, showing where the argument is headed.

In the last five years the United States has moved, albeit for logical reasons that will be explained below, toward an export-control system that could be more complex, costly, and controversial than any we have had before. At the same time Americans remain ambivalent about the objectives of export controls and unclear about what such controls can achieve and what they cannot. Our thinking will be considerably clarified, however, if we bear in mind that the most important question about technology transfer in the long run is whether the receiving side is able to absorb the technology it imports, to diffuse it beyond one or two showcase locations, and to build upon it to generate further technological advances of its own. Only then does technology transfer have its most lasting consequences.

If we rethink the export-control question on that basis, then our focus shifts from the characteristics of the proposed export or its potential end-uses (the issues that the American debate tends to dwell on most) to the Soviets' ability to learn from it. Here we must distinguish between two classes of cases: In certain high-priority sectors (notably military), where Soviet technological skills are already high, the Soviets' ability to learn from foreign technology is also high. Here, then, there is a clear case for export controls. In contrast, in the lagging areas

[1]Previous Rand work on the subject of technology transfer includes: Charles Wolf, Jr., *U.S. Technology Exchange with the Soviet Union: A Summary Report*, The Rand Corporation, R-1520/1-ARPA, August 1974; Robert E. Klitgaard, *National Security and Export Controls*, The Rand Corporation, R-1432-1-ARPA/CIEP, April 1974.

in which most Soviet imports of foreign technology are concentrated, the Soviets' record in absorbing and learning from it is poor. The reasons are much the same as the ones that cause those areas to lag in the first place: They lie deep in the political and economic structure of the country, and (as we shall see) numerous reform measures in Soviet technology policy over the last twelve years have not altered them. Neither have high-technology imports visibly improved the Soviets' ability to innovate on their own, in some instances the opposite. It is this second class of cases, and the difficult matter of distinguishing it from the first, that most of the American uncertainty is about.

This report will argue that within the second class of cases the most effective barriers to technology transfer are those erected by the Soviets against themselves. The effects of internal Soviet obstacles, in fact, dwarf those of the most stringent embargo the Western powers might devise. Consequently, so long as Soviet policies for technological innovation remain as ineffective as they are now, the claimed benefits of any expansion of U.S. export controls should be examined very carefully. Export controls have important if marginal political benefits, as this report will show, but they also have serious costs, and the task before us is to arrive at a sound balance between the two.

Such in brief is the position this report intends to argue. Whether one accepts it or not largely depends on one's view of the Soviet Union as a technological innovator, and consequently much of the report deals in detail with that question. We shall examine the reasons why the Soviet Union has experienced chronic problems with technological innovation; we shall look at the reforms undertaken in the last twelve years and their underlying significance; and we shall inquire into the role of imported technology in the Soviet domestic effort. But first it will be useful to review the recent evolution of American policy on technology transfer, in order to understand its aims and assumptions and to isolate the most important unresolved issues.

It is important to note that one issue that this report deliberately does *not* address is that of employing embargoes or other selective controls on East-West trade as political levers to influence Soviet behavior in the international arena. The issues of "leverage" or "linkage" are far larger questions, raising as they do the use of economic and technological instruments to make important political points, which can be effective as symbolic statements of American positions even if their actual technical effects are minimal. The author of this report does not necessarily quarrel with such uses of export controls; that is a question for the political process to decide. But in making such determinations it is most important to know whether export controls are effective in their *stated* aim (namely, to preserve military lead-times and the national security), to clarify what those aims imply in operational terms, and to know the costs. If this report succeeds in focusing some of the national debate around those basic technical questions, its aim will have been achieved.

EVOLUTION OF AMERICAN EXPORT-CONTROL POLICY

The basis for the present system of controls is the Export Administration Act of 1979 (Public Law 96-72), which mandates prior review and approval by the federal government of any proposed export that "would make a significant contribution to the military potential of any other nation or group of nations which would prove detrimental to the national security of the United States."[2] The agency with primary responsibility for this system is the Commerce

[2] 50 USC2401 et seq. A summary of the provisions and legislative history of the 1979 Act can be found in the *Congressional Quarterly Almanac* for 1979, pp. 300-305.

Department's Office of Export Administration, but several other government offices must also review and concur, notably the Defense Department, which judges the possible military significance of proposed exports. In practice, decisions on controversial cases are made by consensus, which sometimes requires long negotiation to reach.

For the past ten years, the successive versions of the Export Administration Act (the present Act is the fourth since 1969) have been uneasy compromises between two objectives, that of protecting the national security and that of promoting exports. During that period, on the whole, encouragement of foreign trade has been Congress' foremost concern; and framers have attempted to limit and define precisely the situations in which export controls will be invoked. In the past two years, however, anxiety about national security has risen in Congress as in the rest of the nation, and the issue of reconciling the competing objectives in export-control legislation is coming once again to the fore. The matter is complicated by the fact that the distinctions involved are inherently slippery. Just about any export, including feed grain or drilling technology, can be considered a "significant contribution" to Soviet military potential, provided one adopts sufficiently broad definitions. Hence, every time the Act comes before Congress for review (as in 1974, 1977, and 1979), it gives rise to anxious debate.

To try to cope with the distinctions between military and civilian applications of exports, the Departments of Commerce and Defense maintain a Commodity Control List of items with possible military applications. The decision to grant or deny an export license for any item on that list requires judging, case by case, how likely it is that it will actually be diverted to a military end-use and, if the likelihood is considered high, whether suitable checks or alterations can be devised to remove the danger. It goes without saying that this process takes time, and one of the chief complaints of American companies and members of Congress over the years has been that the system is so cumbersome that it costs the United States valuable export business. On that count alone the present export-control system would be controversial. However, the real problems go deeper.

New generations of weapons rest on a multitude of advanced supporting technologies that cannot be said to be inherently either military or civilian. It follows that diversion to military uses constitutes less and less often a clear act that one can identify and control. Even the most plausible diversion scenarios have their ambiguities. Can a Sperry Univac 1100/10C computer, sold to a Soviet design agency in the synthetic-rubber industry, be diverted to perform three-dimensional differential equations for aircraft-wing stress analysis at the nearby Tupolev plant?[3] Amid the flurry of concern over whether it has been or might be, one should point out that synthetic rubber is of military importance too, and that a good eight-year-old computer technology is likely to have a greater marginal impact in that industry than in the top priority Tupolev facility, which presumably is already well provided for.

A further difficulty with the end-use principle, in the eyes of its critics at least, is that it tends to emphasize transfer of "hard" products and processes, physical quantities that can be identifiably diverted, whereas an equally crucial question is the transfer of know-how and supporting skills. In the computer example mentioned above, we worry about the quality of the software that the Soviets may be importing along with the Univac; and diversion of software is, of course, more difficult to spot and deter than that of hardware. Defenders of the present export-control system insist that such know-how and "soft" technology are recognized as problems and are adequately controlled; critics say they are not.

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[3]Peter J. Schuypen, "Soviets' Univac Arouses Concern," *New York Times,* January 3, 1980, p. D1.

Washington's growing awareness of these issues in the mid-1970s led to the development of a new concept and a proposed new strategy based on so-called "critical technologies," which has now been incorporated into official policy in the 1979 Export Administration Act. The term arose out of a panel convened by the Department of Defense in 1975, chaired by the President of Texas Instruments, J. Fred Bucy. The panel's recommendations, issued the following year,[4] contained three important concepts that have since gained wide currency: (1) The proper object of control is the export of manufacturing and design know-how rather than end-products alone; (2) "active" mechanisms of transfer (such as turnkey or training arrangements) are more apt to be consequential than "passive" ones (such as trade fairs or export of finished products); and (3) rather than attempt to construct impermeable barriers to the transfer of militarily significant technology, the aim of the control system should be to retard the flow so as to protect lead-times in the military areas in which the United States has a significant edge.

Each of these three points has important implications. First, by stressing the *mechanism* of transfer, the Bucy criteria stress that the transfer of an object or a process may be less important than the transfer of a skill, and that one of the most important questions about such transfers is the *way* they are made. Second, by focusing on classes of technologies rather than specific items, the Bucy criteria appear to offer relief from the increasingly futile and time-consuming task of tracking down possible military end-uses and diversions. Finally, by emphasizing that the goal of American policy should be to preserve critical lead-times (thus conceding that it is hopeless to prevent military end-uses indefinitely), the Bucy criteria require us to think clearly about the nature and sources of the American lead, in other words, about what technological superiority really consists of in the first place and how it should be defended.

Despite these real virtues, there is serious question whether the critical-technologies approach will improve the export-control system. On the contrary, if we are not careful it could make the system more complex, cumbersome, and controversial than any we have previously had. The "Initial List of Militarily Critical Technologies," issued in October 1980 by the Department of Defense,[5] illustrates the danger. It contains a virtual roll-call of leading contemporary techniques, including videodisk recording, polymeric materials, and many dozens of others equally broad. If this collection had automatically become the basis for the official Commodities Control List (as some had urged during the debate over the 1979 Export Administration Act), the entire Department of Commerce would not have been large enough to administer the export-control program. Fortunately the Initial List has advisory status only, and one may be confident that it will undergo refinement before it becomes the actual basis for policy.

The underlying problem, which the legislative history of the successive versions of the Export Administration Act in the 1970s shows clearly, is that American policymakers have been uncertain about the effects and dangers of high-technology exports to the Soviet bloc.[6] What exactly are we trying to prevent the Soviets from doing? In what ways does imported Western technology enable the Soviets to do the things we fear? Can export controls stop them or slow them down? These three questions are central to any export-control policy, but there

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[4] Department of Defense, Office of the Director of Defense Research and Engineering, *An Analysis of Export Controls of U.S. Technology—A DoD Perspective*, a report of the Defense Science Board Task Force on Export of U.S. Technology, Washington, D.C., February 1976.

[5] *Federal Register*, Vol. 45, No. 192, October 1, 1980, pp. 65014-65019. A recent statement of Dr. Bucy's views will be found in "Technology Transfer and East-West Trade," *International Security*, Vol. 5, No. 3, Winter 1981, pp. 132-151.

[6] Useful background will be found in Organization for Economic Cooperation and Development, Committee for Scientific and Technological Policy, *Technology Transfer Between East and West*, Paris, 1980. See also Marie Lavigne, *Les Relations Economiques Est-Ouest*, Presses Universitaires de France, Paris, 1979.

has been considerable confusion about all three of them. In particular, if our goal is to preserve lead-times it is soon apparent that we have two different sorts of lead-times to worry about: the lead embodied in individual weapons systems and that embodied in the underlying technologies that generate them. Each has its own dangers; and consequently each requires its own sorts of information and its own strategies. What is needed, in other words, is cooler and more systematic thinking about the effects and dangers of technology transfers. In the next subsection this report offers some suggestions.

EFFECTS AND DANGERS OF TECHNOLOGY TRANSFER

In the broadest terms, transfers of technology have three classes of possible consequences: The Soviets may gain (1) direct, near-term military advantage; (2) indirect, longer-term military advantage; (3) a boost to their overall economic growth. Which of these should the United States try to limit through export controls?

Direct, Near-Term Military Advantage

Imported Western technology could yield the Soviet Union a direct, short-term military advantage in two possible ways. The first is a transfer leading directly to a revolutionary Soviet breakthrough. The second is a transfer that suddenly fills a gap, overcomes a bottleneck, or completes a puzzle in an otherwise mature Soviet technology, enabling the Soviets to proceed to a rapid expansion of numbers or a sudden generational improvement in a major weapons system. As a hypothetical example, the revelation of the Ulam-Teller principle, during the crucial period when the Soviets were groping for an efficient fusion-fission coupling of their own, would have been an example of the first kind. A case of the second kind (which we shall discuss in some detail below) may have been the sale to the Soviet Union of high-precision micro-ballbearing grinders, used in the manufacture of highly accurate guidance systems for intercontinental missiles.

A subcategory in the second group is the inadvertent giveaway, in which the technology in question is a readily available item whose military significance the Russians may realize ahead of the Americans. A plausible hypothetical example is Kevlar, the casing material that contains the propellant in the Trident I, initially developed by DuPont for use in radial tires. Kevlar's potential military applications were realized by accident, when defense contractors happened to come across it at an aerospace fair on the West Coast.[7] In this case, the serendipitous discoverers happened to be Americans, but there is no reason why they could not have been Russians. Plastics and synthetic rubber, indeed, have been high on the list of chemicals and chemical equipment purchased by the Soviet Union in recent years. The job of anticipating such cases will become steadily more difficult in years to come, as new weapons systems incorporate a progressively wider range of supporting technologies, such as new synthetic materials and fuels, micro-electronics, and so forth.

As nightmarish as these possibilities sound, it is important to recognize that the chances of a sudden doomsday giveaway through trade are next to nil. First, the military balance between the two countries is stable and well buffered. In strategic weaponry, for example, the

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[7]Deborah Shapley, "Technological Creep and the Arms Race: ICBM Problem a Sleeper," *Science*, Vol. 201, September 22, 1978, p. 1104.

redundancy built into the U.S. Triad is so great that no single new weapon will confer meaningful advantage in the short term. The day when the simple invention of the stirrup swung the balance of power on the Asian continent is long over. (Of course, maintaining the Triad requires periodic deployment of new weapons systems. But such deployments—however heated the debate surrounding them—take decades to plan and execute, which shows how stable the basic system is.)

Second, major weapons systems rest on a multitude of different technologies, so that no single breakthrough will produce a sudden advantage; whether in undersea acoustics, look-down shoot-down air defense, missile guidance, "stealth" avionics or high-energy lasers, major developments come from an accumulation of advances over long years, most of them involving basic sciences that are being actively studied on both sides. Threats from such a quarter can be seen from a long way off, and therefore no single transfer can possibly produce a total surprise. (The enormous publicity given by the Western media to Soviet efforts in charged-particle-beam technology illustrates this point strikingly.)

Third, in the research sectors of immediate military relevance the Soviet Union maintains a level of effort that may be better funded and in some cases more advanced than that of the United States.[8] Most of their weaknesses, as we shall see below, lie in traditionally "civilian," lower-priority, supporting technologies. Experience suggests that in high-priority sectors, in which the opponent is already well equipped and heavily engaged, the most important transfer is simply the sure knowledge that something is possible and is being achieved elsewhere. This appears to have been Fuchs' most important contribution to the Russians, for example, in the case of the hydrogen bomb.[9] Needless to say, the prevention of such transfers, though desirable, lies outside the export-control issue. The same is true of the fact that, where the West possesses a clearly superior technology of direct military importance, the Soviets have demonstrated the ability to spirit away what they need by means other than trade, as in the case of the design for the Sidewinder missile.

In sum, the fear that the United States is unwittingly selling the rope that the Russians will shortly use to hang us is hardly credible. In the areas of technology that might yield direct military advances, the Soviets depend less (and are less willing to depend) on foreign trade than they do in other, traditionally lower-priority areas. No single export item will produce a lightning-bolt surprise, for any such transfer would be so obvious that it could not be overlooked; and even if it were it could not be converted into sudden strategic advantage. It goes without saying that the commercial export of technologies with clear and immediate military applications must be controlled where possible; but despite occasional headlines to the contrary there is no serious evidence that our present control systems (particularly the Munitions List) fail to do this. As we shall see in the next two subsections, the knotty parts of the technology transfer issue lie elsewhere.

Indirect, Long-Term Military Advantage

The more difficult issue in export-control policy is not whether the West is selling the Russians the rope but whether we are selling them the capacity to make it themselves, by

[8]For example, in an address in May 1979 to the Center on Science and International Affairs of Harvard University, Undersecretary of Defense William Perry stated that the Soviet Union may well be investing five times more effort in high-energy laser research than the United States.

[9]See the discussion by Herbert York in *The Advisors: Oppenheimer, Teller, and the Superbomb,* W. H. Freeman, San Francisco, 1976.

helping them to overcome technological lags in the broad industrial infrastructure needed for tomorrow's advanced weapons systems (not to mention tomorrow's economic growth, which we shall address next).

We are currently witnessing throughout the world a blurring of the boundaries between military and civilian technologies, and the Soviet Union is no exception. Tomorrow's weapons systems will depend on new materials and alloys, advances in communications and data processing, manufacturing and fabricating techniques, automation of assembly and auxiliary operations, new skills, and techniques of management. The traditional Soviet strategy of maintaining an isolated high-priority zone for military deployment and production, while simultaneously skimming the cream from the civilian economy for military use, becomes self-defeating when military technology requires the entire range of skills and techniques of an advanced industrial economy.[10] No small part of the current Soviet anxiety over the weaknesses of their R&D policy and their management of technological innovation stems from their increasing awareness of the backwardness of several crucial areas of what had hitherto been neglected as "civilian" technology. Therefore, the greatest benefit of foreign technology to the Soviets may be to bring up to a fully modern standard the "infrastructural" civilian technologies that are emerging as the crucial ones for tomorrow's military strength.

The question is, Can this problem be dealt with through any remotely feasible export-control policy? As soon as one shifts one's focus from weapons systems to the technologies embodied in them, virtually any high-technology product, process, or skill becomes militarily relevant. From there it is but a short step to declare that all advanced technologies should be subject to export controls. The Initial List of Militarily Critical Technologies, mentioned earlier, illustrates the problem: Its critical weakness is that it is simply a listing of techniques that, if exported to a military competitor, *could* be harmful to us; it does not contain any clear conception of how or why technology transfer actually takes place. It implicitly assumes that advanced technology is like virulent disease: It is enough for the recipient to be exposed for him to catch it.

However, studies of actual cases show that that is not how technology transfer works at all. Imported technology will not be of more than passing benefit to the Soviet Union unless that country is able to use it to develop its own innovative capacities, to generate further technology, and to diffuse it broadly and quickly. If the Soviets fail to gain that capacity, then imported technology will in many ways only perpetuate their backwardness and dependence (and we will see instances of that phenomenon in the next section), since by the time it is installed and functioning it is already out of date. *Therefore the crucial point to examine is the extent to which foreign technology helps overcome the root problems that have been holding back Soviet technological innovation in the first place.*

We shall return to that question in the subsequent sections of this report. However there remains one last class of effects to be discussed.

Long-Term Economic Effects: Reinforcement or Displacement?

Foreign technology, whatever else it may do, contributes to the overall growth of the Soviet economy. In the near term, the higher productivity of Western products and processes gives

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[10]In reality, there has always been considerable overlap between the Soviet civilian military sectors, so that what we are really talking about is differences of degree. Nevertheless, in recent years the degree of overlap has greatly increased. See for example Simon Kassel's study of sources of Soviet basic research for laser technology: *The Relationship Between Science and the Military in the Soviet Union,* The Rand Corporation, R-1457-DDRE/ARPA, July 1974. See also a suggestive work by John E. Kiser, III, "Civilian and Military Technology in the USSR: Is There a Difference?" (unpublished).

a boost to quality or efficiency of Soviet output; in some specialties, such as the manufacture of mineral fertilizers, this effect is striking. Over the longer term, Western technology has served as a model and a standard, providing a stimulus to progress that is often lacking within the Soviet system itself.

The contribution of Western technology to Soviet growth may not be large in global terms.[11] But Soviet leaders have frequently used foreign technology to make a fast start in a branch of industry that has suddenly risen in importance and priority; this occurred notably in chemicals in the 1950s and 1960s, in the automotive industry in the 1960s and 1970s, and in the energy sector beginning in the 1970s. Thus foreign technology helps Soviet leaders respond rapidly to new policy needs.

These broad economic effects of foreign technology, rather than the narrower military ones, appear to be uppermost in the minds of the Soviet leaders themselves, for signs of economic trouble confront them wherever they look. Declining output and productivity, shortages of labor and key resources, low quality and poor performance—these are the symptoms of a disease whose existence the Soviet leaders themselves no longer try to deny. And one of the principal remedies to which the leaders have resorted, after lengthy debate and much swallowed pride, has been to import unprecedented quantities of foreign technology.

This development raises the most difficult questions of all for Western export-control policy. Is it in the interest of the United States to try to prevent the Soviet Union from turning to foreign technology to boost economic growth? And if so, are export controls the appropriate instrument for the job? The 1979 Export Administration Act, as we have seen, authorizes the use of export controls to protect the national security, and particularly to prevent transfers that would contribute to the military potential of unfriendly powers. Should fertilizer plants, mills for specialty steels, or oil-drilling technology be banned on the grounds that, because they contribute to Soviet economic growth, they contribute significantly to Soviet military potential? This question has a variant that has proved especially thorny: what if imported technologies free resources that the Soviets can then displace toward the military sector?

Let us take up the latter question first: Its plausibility turns on several difficult questions of fact. First, do we really know that imported technology releases resources? Some Western experts argue, on the contrary, that foreign technology *ties up* scarce resources, because every ruble of imported equipment requires something like five rubles of investment support (in the form of supporting infrastructure and training of personnel), in order to absorb it and make it work.[12] If the priority of the receiving sector is high enough, it may have such a strong claim on scarce resources that it competes with the military.

A more fundamental objection to the displacement argument is that it assumes that the Soviet allocation system treats resources as fungible between the military and civilian sectors. That assumption cannot be demonstrated to be true. What little evidence we have concerning Soviet military spending (and, for that matter, military R&D) suggests a steady, incremental increase through the Brezhnev period, unaffected by the substantial ups and downs of trade in high-technology goods. In other words, there is no evidence that the Soviets would spend less on the military and more on the civilian economy in the absence of high-technology trade. The pattern corresponds instead to what we would expect to observe if the Soviets followed a lexical

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[11]See, for example, the discussion in Philip Hanson, "Western Technology in the Soviet Economy," *Problems of Communism*, Vol. XXVII, No. 6, November-December 1978, pp. 20-30. During the Ninth Five-Year Plan (1971-75) 15 percent of the capital equipment installed was obtained from abroad, although not all, by any means, from the West. See *Izvestiia*, February 18, 1976, cited in A. I. Bel'chuk, ed., *Novyi etap ekonomicheskogo sotrudnichestva SSSR s razvitymi kapitalisticheskimi stranami*, "Nauka," Moscow, 1978, p. 7.

[12]Some Soviet sources make the same point. See Bel'chuk, op. cit., p. 14.

decision rule, with the military treated as first claimant until its "needs" (however defined) are met, and other claimants treated as residual.[13]

The displacement argument, furthermore, assumes that the civilian and military sectors are separate and competitive rather than complementary and mutually reinforcing. But is not an increase in oil drilling in Western Siberia as much a contribution to the military, in the long run, as it is to the "civilian" economy? Imported technology in recent years has been concentrated primarily in industries that the Soviets have been systematically building up rather than deliberately neglecting, industries to which the Soviets are simultaneously directing considerable native R&D. There is no denying that the military sector enjoys the highest priority in the land. What cannot be shown, however, is that the Soviets use foreign technology to wring every last kopeck from the civilian economy to benefit the military.

Still, there is no doubt that the extreme priority enjoyed by the military in the allocation of Soviet resources puts the rest of the economy under severe strain. If that strain became great enough, might not the Soviet leaders be forced to review their priorities and reroute some scarce resources to "civilian" purposes, the energy sector for example? Why then should the West help relieve the strain? An answer one sometimes hears is that, regardless of what happens to the military sector, a technologically backward or energy-starved Soviet Union is a special danger to the rest of the world. Consequently, in this view, it is not in the interest of the West to attempt to impede Soviet economic growth. But is it really true that the Soviets are depraved because they are deprived? There is no particular evidence either way. What stands out, instead, is the essential continuity of Soviet foreign policy over the years, through good economic times and bad. In sum, as one picks one's way through the thicket of arguments about Soviet economic growth, one reaches no clear answers.

Therefore let us reason instead from the standpoint of feasibility. Even if we should *like* to slow down Soviet economic growth (not necessarily a foregone proposition), it is quite another matter to ask whether we *can,* and whether export controls (or even embargoes) are the right instrument for the job. Here it is important to remember that the effects of export controls are inherently marginal. That is, they will not halt Soviet economic or military development; at most, they may slow it down slightly at the margin. (American defense planners mean nothing different when they speak of preserving this country's military lead-time; that is the same as a moving margin.) And as in any public policy, the sound aim is equilibrium at the margin, that is, to confine export controls to the classes of cases in which the marginal political benefits are readily identifiable and outweigh (or at least balance) the marginal political costs of obtaining them.

What happens if we apply this criterion to the three classes of effects of technology transfer that we have been discussing? The benefits of attempting to control near-term military effects are *immediate* and *specific;* those of controlling long-term economic effects are *remote* and *diffuse.* At the same time, the costs of the former are likely to be lower than those of the latter, since they are more likely to command the agreement of our allies and more likely to involve technologies in which the United States is genuinely dominant. It follows that, *from the standpoint of feasibility,* a system of controls narrowly defined around the prevention of near-term military effects is the one most likely to have results, while one broadly aimed at impeding Soviet economic growth is likely to be self-defeating.

But what about the middle category, that of long-term and indirect military effects? Here we need to ask one more question: How *consequential* are the effects of technology transfer in

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[13]We have benefited from the careful discussion of displacement and fungibility in Klitgaard, op. cit., pp. 27-35.

each category? Near-term military effects, as alarming as they are, are nevertheless passing, because the military technologies of both countries are moving rapidly. What *really* maintains lead-times is the comparative ability of both countries to generate new advances, and here it is the long-term effects of technology transfer that may be the most consequential ones, if they affect that comparative ability to innovate. Consequently, the case for export controls in this middle category must turn on evidence that a proposed export package would help the Soviets remove fundamental obstacles standing in the way of their own innovative ability, in some way that the Americans are in a unique position to deny. Whether there exists such evidence is the main question addressed in the rest of this report.

To illustrate and sum up this discussion, let us reconsider a famous case: the decision to allow the export to the Soviet Union of precision grinders for the manufacture of micro-ballbearings, an essential component in advanced guidance systems for intercontinental ballistic missiles.

A Famous Case: The Sale of Micro-Ballbearing Grinders to the USSR

In August 1972, after much internal debate within the American government, the Department of Commerce approved the sale to the Soviet Union of 168 precision machines manufactured by the Bryant Grinder Corporation of Vermont.[14] Micro-ballbearings find many applications in commercial aircraft and other civilian uses. They also play a crucial role in the three-gimbal high-precision gyroscopes used in the current generation of long-range missiles of both the United States and the USSR.[15] The approval of the Bryant grinders sale, together with the fact that the Soviets began the first flight tests of MIRVed missiles less than a year later, touched off accusations at the time that without the imported machines the Soviet Union could not have gone into production of the new missiles.[16]

The official view of the intelligence agencies today is that the Bryant grinders arrived in the Soviet Union too late to have played a crucial gap-filling role in the development of the Soviet fourth-generation missiles. Moreover, the Soviets already possessed similar foreign machines before 1972, purchased from non-American manufacturers; even at the time of the sale the Bryant grinders were no longer the most precise or advanced grinders available, as evidenced by the fact that some American firms at the time were already using Japanese grinders made by Seiko Seiki.[17] Nevertheless, some continue to feel that the case demonstrates the perilous holes in the American export-control system, and insist that the "machines are making a distinctive contribution to the Soviet military effort and could very well be producing the precision miniature ballbearings used in current and follow-on high-quality MIRV guidance systems."[18]

At the time of the Bryant case, the Soviets already had some experience in micro-ballbearing manufacture, but much of it was semi-artisanal. As one Soviet professor acknowledged in

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[14]The Bryant grinders case is discussed in some detail in U.S. Congress (House), Committee on International Relations, *Export Licensing of Advanced Technology: A Review,* Part II, U.S. Government Printing Office, Washington, D.C., 1976, pp. 5-7, 13-17, and 25.

[15]Shapley, op. cit., p. 1103.

[16]Statement by Retired General Daniel Graham, former head of the Defense Intelligence Agency, as reported in Dan Morgan, "U.S. Reportedly Sold Soviets Means to Make MIRV Part," *Washington Post,* February 26, 1976, p. A3.

[17]See the House Committee Report, op. cit.

[18]See also Dr. Miles Costick's testimony before the House Armed Services Committee, reported in *Defense and Foreign Affairs Daily,* June 11, 1979; testimony by Dr. Jack Vorona, Assistant Vice-Director for Scientific and Technical Intelligence in the Defense Intelligence Agency, before the Senate Armed Services Committee, ibid., November 14, 1979.

Izvestiia, Soviet-made grinders in the early 1970s were not precise.[19] "Until quite recently," says another Soviet expert, they were forced to rely on highly qualified workers using "essentially manual" methods for the final polishing and finishing of micro-ballbearings, coupled with a rigorous inspection system that rejected a high proportion of the output.[20] At the Il'ich Machine-Tool Factory in Leningrad, the main Soviet producer, an attempt to develop high-precision machine tools with sub-micron tolerances had ended in failure in the late 1950s, and nothing had been done since. By the late 1960s, says a recent newspaper story,

> the factory was closer to the preparation of simple grindstones and breechblocks for machine guns than to the inconceivable precision of instruments. . . . For the long years that passed from the time of the unsuccessful attempt, there occurred no breakthroughs of any kind at the factory or in the Sverdlov Machine-Tool Association to which it belonged. And the people there remained basically as before and no one had any technical inspiration.[21]

It was around this time that the president of the Bryant Grinder Company visited the Il'ich factory. According to the same newspaper account,

> He walked around all of the factory shops and came away in a good frame of mind. He became animated and candid:
>
> "My impression? I could give you drawings of all our machine tools but you would gain nothing. You cannot make machine tools for manufacturing instrument bearings with such technology, with such equipment and materials, and with such personnel."
>
> The "personnel" frowned but looked at the Bryant president with interest. When Bryant was mastering precision and conquering markets and growing rich, these "personnel" were boys and were making breechblocks for machine guns under the inconceivable conditions of the Leningrad blockade.

The Soviets were in a difficult position. Imported high-precision machine tools were costing tens of millions of dollars every year in scarce hard currency, and unfilled orders for ballbearings were piling up.[22] Worse, their dependence on foreign technology for such an important class of components was perceived as a political liability:

> Bryant could rejoice and not fear competition. It asked vast sums for its outstanding machine tools—$75,000 each. . . . However, there were also other, non-arithmetical considerations. The Bryant firm could trade with us but could also not trade—for political reasons.

One glimpses in this account a not-uncommon Soviet scene: outmoded plant, underqualified artisans set in traditional ways, managers with little incentive to innovate, and a history

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[19] A. Murashkin, Professor at the Leningrad Polytechnical Institute, "Sverkhvysokaia tochnost'," *Izvestiia,* July 15, 1979, p. 2.

[20] Iu. Tarbeev (Director-General of the scientific-production association (nauchno-proizvodstvennoe ob"edinenie) or NPO "VNIIM," Leningrad), "Osoboi tochnosti," *Pravda,* September 6, 1979. The Americans have a similar problem. In 1976, Edwin Speaker of the DIA had the following comment on rejection rates: ". . . If you look at the probable number of precision bearings that have to go into each missile guidance system and make a reasonable judgment as to what the rejection rate is of your best bearings, it is something like 9 out of 10 bearings sets have to be rejected because of the difficulty of producing the really good ones. That is a process we use in this country. We produce 10 bearings and then pick the best ones and it is about one-tenth of gross production. So it is a very expensive process." His comment is in the House Committee Report, op. cit., p. 16.

[21] Ia. Strugach, "The Logic of Victory," *Leningradskaia Pravda,* November 11, 1980. Translated in *Joint Publications Research Service,* No. 77305, February 3, 1981, pp. 1-8.

[22] During the period 1971-1975, the Soviets claim to have spent 215 million "exchange rubles" for machine tools for instrument bearings. See Strugach, op. cit.

of dependence on foreign technology. Yet within less than a decade, or so the Soviets claim, the situation was utterly transformed: they report that they have developed their own high-precision machine tools capable of grinding the raceways of miniature ballbearings to tolerances of two ten-thousandths of a millimeter.[23] This new line of mass-produced machine tools has made it possible to eliminate the backlog of orders for precision ballbearings in less than two years, and was evidently considered successful enough to be advanced as a candidate for a State Prize.[24] The newly mastered technology allows closer tolerances than Western equipment, and one Soviet source claims it has earned the Soviets patents in several major countries, including the United States.[25] Most important, it has made further imports unnecessary.

Now, assuming the Soviet accounts have any truth to them, what new light do they put on the Bryant grinders case? First, the articles confirm that around the time of the Bryant grinders sale the Soviets could not meet the necessary close tolerances for mass manufacture of micro-ballbearings.[26] Therefore one may surmise that the Soviets did indeed derive a direct, short-term gain from foreign technology, though possibly most of all among nonmilitary customers who had been obliged to accept second-quality output. It cannot be excluded that the Soviets derived a military benefit as well, although not (because they arrived late) from the Bryant grinders themselves. But it may be argued that that fact in itself is not the most significant part of the story, for the direct short-term gain that the Soviets may have realized was at best passing. The real news is that the Soviets now claim to have equalled or bettered Western capabilities, a development that affects not only missile accuracy but Soviet capabilities wherever precision ballbearings may be used. What happened to produce such a startling change, and what role did Western technology play in overcoming obstacles?

The most important initial step, apparently, was to put sufficient political priority behind the project, and in that sense what follows is a familiar Soviet scenario, which we shall discuss more systematically in the next section. High-level political interest was evident from the first: around 1970 the head of the special design bureau of the Il'ich plant, together with the managers of the factory and the parent Sverdlov Association, were summoned to Moscow for consultations at the CPSU Central Committee, the Council of Ministers, and the State Planning Committee (Gosplan). But there was considerable hesitation in high places:

> Our work began in difficult circumstances [relates the head of the special design bureau]. They did not believe that we, the developers, could create our own original machine tools and no worse than Bryant's. And we the designers, in turn, did not believe that the factory could produce such precise equipment. No, this was not skepticism relating to one another's capabilities. We could not in those years risk giving up purchasing imported equipment while we still did not have our own. . . .

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[23]Murashkin, op. cit. See David Holloway, "Military Technology," in Ronald Amann, J. M. Cooper, and R. W. Davies, eds., *The Technological Level of Soviet Industry*, Yale University Press, New Haven, Connecticut, 1977, p. 472.

[24]However, it apparently did not succeed, because it was not mentioned in the published list of recipients of State Prizes for 1979.

[25]At the basis of the new technology, according to Professor Murashkin, is the use of ultrasonic waves, which make it possible to use diamond-chip cutting wheels with the necessary stability and governability. In addition, use of ultrasonic waves, directed at the spindle about which the bearing rotates during manufacture, has made it possible to cut vibration between the bearing and its spindle by a factor of a hundred. New optical methods were developed to supervise the grinders' operation. All in all, the new technology led to thirteen Soviet patents (*avtorskie svidetel'stva*), but Murashkin (unlike Tarbeev) mentions no foreign ones.

[26]In addition, the rate of output was not sufficient to meet their needs. In 1976, Edwin Speaker of the Defense Intelligence Agency stated, "We know that the Soviets have produced reasonably good gyroscopes and accelerometers which have been flown in ICBMs prior to the sale of these grinding machines." House Committee Report, op. cit., p. 6. Mr. Speaker subsequently added, ". . . to produce the quantities would require full capacity to a fairly large national production capability just to support, say, the SS-19 program. . . ." (p. 16).

> At the 25th. Party Congress (1971) and at the drafting of the country's 9th. Five-Year Plan, this question among others of state importance was debated: Should we buy machine tools abroad or begin our own domestic manufacture?. . .
>
> Opinions on the subject were varied; we will omit the heat and conflict and say only that it was decided to try again to create machine tools.

We see here, incidentally, another familiar theme: The skepticism of higher authorities about the capabilities of their own people has long been a sore point among Soviet technical personnel, as well as a source of real difficulties to them.[28] At any rate, the 1971 decision was evidently still a somewhat tentative one, for the project was not written into the Main Guidelines of the Ninth Five-Year Plan (that did not happen until the Tenth), and the personnel of the Sverdlov Association were under constant high-level pressure to prove what they could do. By around 1974, they had something to show:

> At the factory there soon stood six machine tools: two Bryants, two of the first domestics, and two exact copies of the American ones. (They were able to make them in the shops.) A specially created commission visited [from Moscow]. Stocks of bearing rings were brought in. The machine tools passed the test. All six worked. Our first models rivaled the foreign ones and did not lag behind them.
>
> The cautious commission made a rare decision: They considered it possible to permit trials for domestic machine tools.
>
> With many difficulties, which meant doing it by hand, during the span of two years 1975 and 1976, ten machine tools were prepared at the factory—the whole gamut of equipment for manufacturing instrument bearings.[29]

That was the first big step, and on the strength of it the project was written into the Main Guidelines for the Tenth Five-Year Plan, in late 1975. Still, the most difficult part lay ahead: to go from a handmade prototype to a series model. This is consistently one of the most troublesome spots in the Soviet R&D cycle; indeed, most of what is officially reported as innovation in the Soviet Union consists of designs that are never produced in more than ten copies. (This point is discussed later in this report.) But by 1977 the Il'ich plant had produced 53 of the new machine tools, and in the following year another factory (the State Ballbearing Plant No. 5, also located in Leningrad) joined in. In 1978, output reached 209 units, and in 1979, 234.[30]

What lies behind this apparent success? Rapid progress appears to have come once a sufficiently high-level coordinating group was appointed to bring together the organizations working at different points of the R&D cycle, particularly some basic-research institutes.[31] Another key element was the extra financial support and management attention that high

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[27]Strugach, op. cit.

[28]See for example the memoirs of a former Soviet electronics expert who was involved in military R&D until his defection in 1971. A. Fedoseev, *Zapadnia,* Frankfurt: Possev, 1976.

[29]Strugach, op. cit.

[30]Strugach, op. cit.

[31]Tarbeev mentions: (1) the Special Design Bureau for Polishing Equipment (SKB shlifoval'nogo oborudovaniia), (2) the Sverdlov Machine-Tool Association (stankostroitel'noe ob"edinenie imeni Sverdlova), (3) the All-Union Scientific Research Institute for Abrasives and Polishing (Vsesoiuznyi nauchno-issledovatel'skii institut abrazivov i shlifovaniia), and (4) the State Ballbearing Factories Nos. 4 and 5. Finally, the writer himself is director-general of the Mendeleev Science-and-Production Association (NPO VNIIM imeni Mendeleeva). All of these organizations are located in Leningrad.

political priority made possible. This proved to be especially important at the stage of developing series production: the Ministry of Instruments (Minipribor) provided additional millions at this point, and relieved the Il'ich factory of some other production assignments. Something like the well-known Hawthorne Effect seems to have spurred the efforts of the workers at the Il'ich plant, a by-product of high-level attention.[32]

What caused the Soviets to commit themselves to the machine-tool project when they did? The timing of the final go-ahead, coinciding as it did with the deterioration of U.S.-Soviet commercial relations in 1974-1975, could lead one to speculate that the essential stimulus for the Soviet effort was the threat that the foreign supply might be cut off. However, our brief look at the history of the decision shows that the actual reasons were more complicated, beginning with the fact that the initial Soviet decisions were made in 1971, when detente was at its height and U.S.-Soviet trade was on the verge of a major expansion. It is perhaps closer to the truth to say that the Soviet move was motivated by the rapidly growing demand for micro-ballbearings in Soviet industry and the growing liabilities of importing them, and not by any particular event in the West.

This glimpse at the Soviet context of a controversial case, precisely because it raises more questions than it answers, underscores the fact that implementing a sound export-control policy requires more attention to the sources of Soviet problems, to the range of Soviet efforts to overcome them, and to the role of foreign technology transfer in that process. These three questions, then, are the subject of the next five parts of this report, following which we shall return to the policy implications of the findings.

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[32]Strugach, op. cit.

II. SOVIET PROBLEMS WITH TECHNOLOGICAL INNOVATION: PRELIMINARY COMMENTS ABOUT THE COMMAND ECONOMY

The central proposition advanced in the Introduction was that high-technology transfers to the Soviet Union should be evaluated, first and foremost, according to whether they enable the Soviets to compensate for the root problems that hold back much of their technology. To do that we need to know more about what those problems are and what the Soviet leaders are attempting to do about them. At the same time, we should recall that technological innovation in the Soviet Union is only a special case of a worldwide and still imperfectly understood phenomenon, namely, that of translating new ideas into new applications.

For the reader who may not be familiar with the details of the Soviet command economy, it will be helpful to explain briefly the structure of incentives, signals, and constraints under which Soviet managers operate. This is important because we shall have occasion to talk about such concepts as "demand," "supply," and "barriers" as they affect innovation, and the reader who is accustomed to these terms in the context of a mixed economy such as that of the United States may reasonably wonder what they mean in the Soviet context. Hence a few preliminary guideposts.

A first key point about the command economy is the extent to which it displaces economic signals with political and administrative ones. Soviet managers are not rewarded for maximizing profits or for capturing a larger share of a market, but for meeting a complicated mix of administratively determined performance targets. The different targets in the mix are not necessarily consistent with one another; it is the rule, rather than the exception, that they cannot all be met simultaneously. Soviet managers have every incentive to concentrate on the ones that will earn them their bonuses and preserve their jobs, and those are usually the targets related to gross output.

For managers and ministers alike the annual plans are so taut, and the problems of meeting the basic ones so all-consuming, that there is little leisure for longer-range thinking. The successful Soviet executive is an expert at cutting corners and at knowing what can be allowed to slide if necessary. The remarkable thing is that this psychology holds not only at the local levels but also at the higher ones.[1] The result is an ingrained bias throughout the industrial system toward a conservative, risk-averse form of behavior. The bias can be overcome (as we shall see below) but it is always there.

The incentives created by the system of performance targets dilute the motivating force of prices. Soviet prices are themselves administratively determined quantities, whose function is not so much to signal the terms of trade between supply and demand as to serve a host of policy purposes. Consequently, the fact that Soviet managers do not react to prices alone is perhaps a fortunate thing, because Soviet prices often produce unintended side-effects that might be worse if managers responded to prices more. For example, producers are often rewarded for innovating by being allowed to charge a higher price for their product, regardless of the

[1]The local unit of production is typically called, in Soviet parlance, the enterprise. The next unit up the administrative hierarchy is called an association, while an entire industry such as gas or oil is managed by a ministry.

increased productivity the innovation may generate. One might expect this fact to depress demand by users, but in a seller's market like the Soviet Union the buyer often has no choice but to acquire the new product, and because of a perverse property of the target system, the buyer is often rewarded for using *higher*-priced inputs.

In sum, though the Soviet manager acts as "economic man" no less than his Western counterparts, the signals and incentives surrounding him cause him to behave in ways that work against sound innovation. The traditional target mix typically discourages all innovation; and if an innovation target is added to the mix neither producers nor users have the necessary information and incentives (such as a market system provides) to tell a good innovation from a bad one.

SUPPLY, DEMAND, AND BARRIERS TO INNOVATION IN THE SOVIET ECONOMY

It follows that the familiar concepts of supply and demand, and the process by which they meet, must be thought of somewhat differently in the Soviet context, particularly as they affect technological innovation. The basic source of "supply" for innovation is not fundamentally different from what it is in the West, in the sense that it consists of the stock of new ideas and combinations of ideas that constitute the potential for something new. There is no lack of these in the Soviet Union. The chief difference lies in the mysterious ingredient that we call entrepreneurship. Most Soviet managers are not trained or encouraged to be innovative entrepreneurs but resourceful plan-meeters, and most Soviet scientists or designers have no incentive or material support to become producers. Finally, to the extent that innovation requires new materials or skills, rigidities in the system of material supply and training (inherent in a seller's market in which manpower is short) further hinder the supply of new technology.

On the demand side, there are two aspects to consider: first, incentives and signals that create a demand for a producer to develop and introduce something new; and second, those which create a demand for the user to adopt it, choosing wisely among the alternatives that may be offered. In an ideal market economy, those two elements of demand are closely connected to one another, as indeed they should be, for otherwise what is the use of innovating? But in the command economy that connection is severed. The stimulus for innovation does not come from a market opportunity, for no Soviet manager or inventor or user stands to profit much. On the contrary: Since bonuses are tied to current output targets, there are stiff penalties for failing to meet them; retooling is difficult and slow; the prices assigned to new output rarely compensate the innovating enterprise for its costs and its risks; and most of all, most enterprises enjoy a stable seller's market that puts no pressure on them to compete or change. In sum, for most Soviet industries innovation is uncertain, unprofitable and unnecessary.[2] New products and processes, if developed, commonly find only one producer if any; and once in production, they diffuse slowly.[3]

Consequently, the demand for innovation is administrative: Innovations (both the development and the adoption of them) are assigned from above, usually on the basis of recommendations by teams of scientific advisers or committees of engineers reviewing developments abroad. To give the producer an incentive to respond to the command to innovate, he may be given an

[2] See Joseph S. Berliner, *The Innovation Decision in Soviet Industry,* M.I.T. Press, Cambridge, Massachusetts, 1976.
[3] R. W. Davies, "The Technological Level of Soviet Industry: An Overview," in Amann, Cooper, and Davies, op. cit., pp. 47-58.

annual innovation target, or a guaranteed higher price for his new product. That guaranteed return, together with the prevailing seller's market for most output in the Soviet Union, means that the Soviet system, once it succeeds in stimulating innovation at all, is particularly vulnerable to pseudo-innovation and gold-plating.[4]

Finally, there are several kinds of barriers and gaps separating the developers from the users of new ideas. The successive stages of the research, development, and innovation cycle in much of the civilian economy commonly belong to separate institutions, to different administrations within the same ministry, or sometimes different ministries altogether. The best basic research and no small part of the highest-priority applied research are the province of the Academy of Sciences, while most industrial research and development is subordinated to ministry directorates for science and technology (*nauchno-tecknicheskie upravleniia*) that have no direct stake in their own ministries' performance, especially since the latter is still evaluated primarily on the basis of targets related to gross output.[5] The flow of ideas, manpower, and supplies across these institutional gaps is impeded by requirements for visas and authorizations at every stage, and in addition by conflicting outlooks and interests, especially where two or more separate ministries are involved.[6]

Activities situated at the boundary between research and production tend to be particularly neglected, because facilities for testing, pilot production, and demonstration tend to be underfunded and subject to diversion to meet current production targets. Compounding the problem of barriers and gaps is a general underdevelopment of copying and communications technology, difficulties arising from inconvenient or impeded travel, obstacles to labor mobility (notably housing problems), secrecy where classified research is involved, and delays and restrictions in publication. The result is serious failure of communication between potential innovations and potential users, and ignorance about what is being invented elsewhere in the country or could be.

UNDERSTANDING SOVIET TECHNOLOGICAL PROBLEMS: INSIGHTS OF SOVIET AND WESTERN LITERATURE

Which of these three problems—supply, demand, and barriers—is the most important for understanding Soviet problems and the roles of Western technology? This is, of course, one of the most pressing questions for present-day economies around the world. Which is the most

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[4]On excessively high-priced innovation, see Central Intelligence Agency, National Foreign Assessment Center, *An Analysis of the Behavior of Soviet Machinery Prices 1960-1973,* ER 79-10631, Washington, D.C., December 1979. On the concept of service to users of new products, see M. E. Tsaregorodtsev and V. L. Kvint, "NPO otvechaet za vse: razrabotka, proizvodstvo, montazh, obsluzhivanie," *Ekonomika i organizatsiia promyshlennogo proizvodstva,* No. 10, 1979, pp. 100-114, which contains an account of the efforts of a scientific-production association to develop a full package concept for its products. Similarly, one finds discussion in the Soviet press of the efforts of the Ministry of Instrument-Making to develop service teams for its computers. Iu. Lapshin, "Put' koroche: vychislitel'naia tekhnika i kontsentratsiia proizvodstva," *Sotsialististicheskaia Industriia,* September 1, 1976.

[5]For basic science, see Thane Gustafson, "Why Doesn't Soviet Basic Science Do Better?," in Linda Lubrano and Susan Solomon, eds., *Soviet Science and Technology in Social Context,* Westview Press, Boulder, Colorado, 1980, pp. 31-67. For information on applied science institutes and design bureaus, see E. Zaleski et al., *Science Policy in the USSR,* Organization for Economic Cooperation and Development, Paris, 1969, pp. 381-490. For useful historical background, see Kendall E. Bailes, *Technology and Society under Lenin and Stalin,* Chapters 11, 12, and 13, Princeton University Press, Princeton, N.J., 1978; and Bruce Parrott, "Technology and Soviet Policy: The Problem of Industrial Innovation, 1928 to 1976," Ph.D. dissertation, Columbia University, 1976. A revised version of the latter work will soon be published by M.I.T. Press.

[6]For one example among many, see Iu. E. Nesterikhin, "Novaia forma integratsii nauki i proizvodstva," *Ekonomika i organizatsiia promyshlennogo proizvodstva,* No. 3, 1975, pp. 53-64. Academician Nesterikhin is discussing the effects of barriers across ministries on the development of new digital scientific instruments and apparatus.

important element in technological innovation: the demand for new ideas, the supply through research and discovery, or the communication between the two? The Western literature on this question as well as its Soviet counterpart are both huge. In the Western literature there has been a definite evolution of views over the last quarter century, the result of a steady accumulation of case studies drawn from many different branches of science and technology.[7]

The first generation of studies of innovation, during the 1950s and 1960s, saw it as a linear, unidirectional process, initiated by discoveries in basic research, and flowing from there to applied research, development, and new production.[8] This early conception proved inadequate, for it failed to account for more than a handful of actual cases, although they happened to include some very important ones.

In reaction to the "science-push" linear model, there followed a wave of studies arguing precisely the opposite, that demand for new products and processes from users and producers tends to be more important than scientific advances and technological opportunities in accounting for successful innovation.[9] But lately there has been a reaction against this "demand-pull" conception also, on the grounds that it too is an oversimplification. Demand does not just "pull" innovations along, it also screens out the less valuable ones. Even more important, recent studies based on a reexamination and critique of past case studies,[10] analysis of citation data, and direct investigation of what one might call the organizational anthropology of innovation[11] bring out a complex pattern, in which the exact nature of the synthesis between demand-pull and discovery-push, and the exact proportions of each in the mixture, turn out to depend on which technologies and branches of industry one happens to be talking about, what their degree of maturity is, and whether the innovation in question is major or minor. The pathways by which new scientific and technological ideas meet opportunities for applying them are increasingly seen not as straight lines but as complex networks with multiple feedback channels, in which informal communications and informal roles play a vital part.[12]

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[7]Among the surveys, see C. W. Sherwin and R. S. Isenson, "Project Hindsight," *Science*, Vol. 156, June 23, 1967, pp. 1571-1577, which contains an account of findings for the Department of Defense, tending to show that scientific discovery played a relatively minor role in the key advances leading to new weapons systems. For two attempts at a rebuttal sponsored by the National Science Foundation, see Illinois Institute of Technology, *Technology in Retrospect and Critical Events in Science*, Chicago, Illinois, 1968; and Battelle Columbus Laboratories, *Interactions of Science and Technology in the Innovation Process: Some Case Studies (Final Report)*, Columbus, Ohio, 1973. Among more detailed case studies one may consult Ernest Braun and Stuart McDonald, *Revolution in Miniature: The History and Impact of Semiconductor Electronics*, Cambridge University Press, Cambridge, 1978, which argues for a cyclical view of the relative importance of science-push and need-pull, while at the same time stressing that "no invention or innovation has ever owed more to pure, abstract science." Analyzing the same field by means of citation analysis, Marvin Lieberman also finds evidence for a cyclical relationship. See his "A Literature Citation Study of Science-Technology Coupling in Electronics," *Proceedings of the IEEE*, Vol. 66, No. 1, January 1978, pp. 5-13. Still other case studies on the relationship of need to discovery in electronics are Hugh G. J. Aitken, *Syntony and Spark: The Origins of Radio*, Wiley and Sons, New York, 1976; A. M. Golding, *The Semiconductor Industry in Britain and the United States: A Case Study in Innovation, Growth, and Diffusion of New Technology*, D.Phil. thesis, University of Sussex, 1971; and J. F. Tilton, *International Diffusion of Technology: The Case of Semiconductors*, The Brookings Institution, Washington, D.C., 1971.

[8]For a review and a critique, see E. A. Haeffner, "The Innovation Process," *Technology Review*, March/April 1973, pp. 18-25.

[9]The main empirical studies upon which this view is based include J. Langrish, M. Gibbons, W. G. Evans, and F. R. Jevons, *Wealth from Knowledge*, Macmillan, London, 1972; and J. R. Schmookler, *Invention and Economic Growth*, Harvard University Press, Cambridge, Massachusetts, 1966. The implications of these studies are summed up in what is perhaps the strongest statement of the "demand-pull" viewpoint, Robert Gilpin, *Technology, Economic Growth, and Economic Competitiveness*, study prepared for the Subcommittee on Economic Growth of the Congressional Joint Economic Committee, U.S. Government Printing Office, Washington, D.C., 1975.

[10]David Mowery and Nathan Rosenberg, "The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies," *Research Policy*, Vol. 8, 1979, pp. 102-153.

[11]Thomas J. Allen, *Managing the Flow of Technology*, M.I.T. Press, Cambridge, Massachusetts, 1977.

[12]See, for example, D. G. Marquis and T. J. Allen, "Communication Patterns in Applied Technology," *American Psychologist*, Vol. 21, 1966, pp. 1052-1060.

American experience also shows the crucial importance of the relationship between the innovating producer and the final user, for the ultimate success of an innovation depends on its wide acceptance. Still another concept much discussed in the United States is that high-technology systems must be developed as a *package,* in which maintenance, training, spare parts, and later improvements must all be considered as a whole.

The Soviet literature has tended to follow a similar evolution, although statements of the "discovery-push" view still tend to be more common than in the West,[13] and there is more stress on the importance of gaps and obstacles between the demand and supply of new ideas, reflecting the special features of the Soviet system. But the most interesting development in the Soviet literature in recent years is the growing recognition of the importance of demand factors, and increasing awareness of the "package" concept as a key to success.

A random sample of Soviet success stories shows these new concerns clearly, and also shows that the Soviet commentators are well aware of the complexities of each individual case. The Soviet development of synthetic diamonds, for example, was initiated on high-priority demand from the top of the government, stimulated by a Western embargo on sales of industrial diamonds.[14] The nuclear-power and ship-building industries played a strong role in stimulating the use of plasma for cutting and working metal, especially for high alloys that could not be cut efficiently with standard machine tools.[15] The needs of the automobile industry led to the rapid development of powder metallurgy, despite the slowness of the Ministry of Ferrous Metallurgy to supply suitable iron powder and what has been described as the lack of productive ideas coming from the research institutes working in that area.[16]

Conversely, one also finds Soviet discussions that show a growing awareness that all is not well in the demand area. For example, industrial application of explosion welding, first invented by hydrodynamic specialists in a laboratory of the Academy of Sciences, has been slowed down for over 15 years by the conservatism of potential users, except for the hydropower and nuclear-power industries, where the technique has been successfully used.[17] One of the most striking examples of demand failure comes from Deputy Minister of Foreign Trade N. Smeliakov who observes that the Japanese have built two new slabbing plants under Soviet license, using Soviet-developed advances for continuous steel casting which the USSR Ministry of Ferrous Metallurgy has so far failed to implement at home.[18]

Such examples could be multiplied. But of late the Soviet literature has been showing an increasingly sophisticated understanding that what is required is not simply demand for

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[13]Some older scientists in particular feel that both the burden and the responsibility rest with the scientist, especially the basic scientist. See for example an article by the late Academician L. Vereshchagin, "Moral'nyi veksel' uchenogo," *Znamiia,* Vol. 6, 1977, pp. 194-204. He portrays the relationship between scientists and industrialists as tense and conflict-ridden, one in which the scientists have every difficulty in gaining the confidence of industrial managers, only to find that it is easily lost again. But the responsibility for bridging the gap must rest primarily with the scientist, Vereshchagin believes, who thus shows his belief that the path of innovation runs mainly from discovery to the subsequent identification of needed applications. In particular, Vereshchagin writes, there should be more scientific popularization. The perfect example is the laser, which was so widely publicized in the press that no potential user could have remained ignorant of it.

[14]"Grani chudesnogo kristalla," *Sovetskaia Latviia,* January 13, 1978. The All-Union Diamond Research Institute was created in 1948, and produced the first Soviet synthetic diamonds in 1960, with industrial mass production capability following in 1965. It is interesting to note that the discovery of large diamond fields in Iakutiia in 1954-55 did not interrupt the effort. The institute's role in the development of a successful line of synthetic diamond-tipped cutting tools for the auto industry was awarded the State Prize in 1977.

[15]Interview with V. N. Bogdanov, Director of the All-Union Research, Design, and Engineering Institute for Electro-Welding Equipment, "Plazma prishla v tsekh," *Pravda,* November 2, 1978.

[16]V. Koftelev, "Detal'...iz poroshka," *Pravda,* July 28, 1978.

[17]See Zamira Ibragimova, "Tiazhkii put' vnedreniia," *Ekonomika i organizatsiia promyshlennogo proizvodstva,* No. 5, 1973, pp. 37-50; "Vzryv-masterovoi," *Pravda,* May 10, 1978; "Vzryv-metallurg," *Izvestiia,* February 15, 1977.

[18]N. Smeliakov, "Prevoskhodiat mirovye obraztsy," *Pravda,* December 28, 1979.

innovation, but *appropriate* innovation of the kind that will yield users an increase in benefit per unit of cost, thus gaining ready acceptance among users. In other words, the Soviet literature is beginning to grapple seriously with diseases of demand.

As we discuss these problems, we should bear in mind, of course, that in several branches of technology the Soviets innovate very well. The challenge to our understanding, therefore, is to account for the great variety of strengths and weaknesses of innovation in different Soviet industries. The Soviet technological landscape (not to mention that of the United States) is complicated indeed, ranging from valleys of backward technology to summits of world leadership. The very complexity of the topography guarantees that it has no single cause; we can take it as given, therefore, that the relationship of demand-pull to discovery-push, and the obstacles to the transmission of one to the other, will not be quite the same in any two industries or even subbranches of the same industry. What broad patterns can one isolate?

THE IMPORTANCE OF HIGH POLITICAL PRIORITY

One particularly important pattern is the apparent strength and quality of innovation in Soviet military-related technologies. Still looking through the prism of the three categories we have been using, we may ask, what obstacles have the Soviets succeeded in overcoming in military innovation? Western observers agree that the crucial element in the success of military-related fields of science and technology in the Soviet Union is high political priority. But what exactly does priority *do*? Can Soviet reformers duplicate the achievements of high-priority programs in lower-priority environments?

One view is that high priority works by overpowering all three categories of obstacles we have been discussing, and therefore it is an indispensable ingredient for successful innovation in a command economy. It enables military projects to mobilize the best brains and the best resources to overcome administrative obstacles and gaps, and to provide special incentives for innovative behavior. Most of all, high priority allows military customers to exercise demand power in an economy that is largely a seller's market—requiring service by producers, providing feedback from field tests that the producer must respond to, securing reliable sources of supply, and rejecting low-quality or unsuitable innovations. In this view, political priority is both a *necessary and a sufficient* condition for excellent—if very expensive and therefore necessarily restricted—translation of new ideas into high-quality products.[19]

A different view of the effect of high priority in military-related technology is that it provides a nurturing environment within which research institutes, design bureaus, and firms have pioneered (or borrowed extensively, when they did not invent them) managerial devices and incentives that help to overcome the standard ills of civilian innovation.[20] Such managerial innovations include: strong customer representatives located at the contractor's plant; one-roof organizations bringing together R&D and production under single management; extensive use of reliability analysis; programs for the enhancement of product quality (special wage systems, etc.); enforceable contracts; powerful chief designers and entrepreneurial bosses; ad hoc innovation teams; competition at early design stages; network planning of development projects; specification in advance of the producer plant; feedback from users; and full-cycle

[19]Gur Ofer, *The Relative Efficiency of Military Research and Development in the Soviet Union: A Systems Approach*, The Rand Corporation, R-2522-AF, November 1980.

[20]See Robert W. Campbell, "Management Spillovers from Soviet Space and Military Programmes," *Soviet Studies*, Vol. 23, 1972, pp. 586-607; Nancy Nimitz, *The Structure of Soviet Outlays on R&D in 1960 and 1968*, The Rand Corporation, R-1207-DDRE, June 1974, especially pp. 40ff.

program planning that embraces all the steps between research and deployment.[21] In this view, high priority alone is *not a sufficient condition* to account for the superiority of Soviet military technology over civilian.

The question of what high priority does, and whether it is possible for a command economy to stimulate appropriate and sufficient innovation without it (or rather with smaller amounts of it than the military sector has traditionally enjoyed), is one of the most fundamental questions at stake in recent Soviet technology policy. Priority is by definition a scarce resource. Therefore if it is priority, and priority alone, that produces superior Soviet military technology, then superior performance will necessarily be limited to those few sectors that high priority can cover. That would be very bad news for the rest of Soviet industry. On the other hand, if high priority works by creating, in effect, a greenhouse environment for the development of effective management techniques, within which the usual pernicious counterincentives are suspended, then a similar approach might work acceptably in lower-priority environments. The pattern of reforms adopted by the Soviets in the last eleven years shows their belief—or at any rate their hope—that the latter is the case.

This is a fitting time for a preliminary evaluation of those reforms, for the eleven-year period between 1968 and 1979 constitutes a distinct phase in Soviet thinking and experimentation in the management of innovation. The period began optimistically, with a high-level decree in 1968 that launched most of the experimental reforms we shall examine in coming sections: goal-directed program planning, targeted funding, user evaluation, single-roof research-and-development corporations, accelerated development of facilities for development and pilot production, and new organizational arrangements for strengthening the role of pure science in the innovative process.[22] Though the 1968 decree showed serious concern about the economy's innovative performance, it also reflected faith that new patterns of organization and incentives could be created *within the existing ones* stimulating effective innovation without the need for altering the system as a whole.

By 1979, however, innovative performance had not improved; indeed, the 1968 reforms themselves had created additional problems that had not existed before. A second high-level decree appeared, evidence of sober second thoughts.[23] The 1979 decree does not undo the reforms of 1968; in fact, in some respect it extends them by applying them to additional ministries. But it also sounds a new note: that improvements in innovation depend on improvements in the overall system of planning and management. The official outlook in 1979, as compared to 1968, is more restrained and more somber.

In sum, the period from 1968 to 1979 appears to have been an important period of learning, although the lessons that have been drawn from the experience may not become visible until the present leaders have departed. The very variety of the experimental reforms tried during this period testifies to the fact that the Soviets themselves do not agree on what the root problems of innovation are, some stressing improvement of demand-pull, others discovery-push, and others the transmission mechanisms in between; but what all these reforms have behind them is the growing conviction that the key to solving Soviet problems in innovation

[21]Nancy Nimitz, work in progress. See also Robert Campbell, op. cit.

[22]Postanovlenie TsK KPSS i SM SSSR, "O meropriiatiiakh po povysheniiu effektivnosti raboty nauchnykh organizatsii i uskoreniiu ispol'zovaniia v narodnom khoziaistve dostizhenii nauki i tekhniki," Decree No. 760, September 24, 1968. The decree specifically refers to defense needs as one of the motivations for the series of reforms it announces.

[23]CPSU Central Committee and USSR Council of Ministers, "On Improving Planning and Strengthening the Economic Mechanism's Influence in Enhancing Production Efficiency and Work Quality," *Pravda,* July 29, 1979. Trans. in *Current Digest of the Soviet Press (CDSP),* Vol. XXXI, No. 30, August 22, 1979, p. 1.

lies in finding more effective incentives rather then simply manipulating management structures.

THE ROLE OF FOREIGN TECHNOLOGY AND THE WESTERN EXAMPLE

What has been the role of Western technology in this eleven-year evolution? Here we have the foreign-trade counterpart to the question just discussed about priority: What exactly does foreign technology *do*? The similarity between this question and the one raised earlier is not accidental: After all, access to hard currency (one of the scarcest of Soviet resources for much of that country's history) is itself a manifestation of high priority. What do the Soviet leaders use it for?

There are two possible strategies: At one extreme, one may concentrate foreign imports in a handful of backward industries, and attempt to propel them quickly up to the foreign state of the art, by brute force so to speak, through massive purchases of turnkey plants and equipment, use of foreign specialists, and so forth. Or one may try to combine foreign technology (particularly skills and management techniques) with Soviet, using foreign example to stimulate one's own capacities, through joint design and other cooperative arrangements. The Soviets have tried both in varying mixtures, as we can see by comparing recent developments in the chemical, machine-tool, automotive, and computer industries.

The Soviet Chemical Industry

In the chemical industry, the Soviet Union has pursued for twenty years a program of massive imports of equipment and technology, particularly in the areas of synthetic fibers, plastics, fertilizers, and synthetic rubber (see Table 1). So great has the volume of imports been that by the end of the 1970s Western equipment accounted for between two-thirds and the entirety of Soviet output of polyethylene, polypropylene, polyester fiber, and acrylic fibers.[24] This effort began at a time when the Soviets had virtually no industrial experience in these branches of chemistry, which had developed in the West since 1945.[25] However, despite a rapid growth in the number of Soviet engineers and scientists trained in chemistry in the 1960s and 70s and an equally striking increase in the number of chemistry research institutes, it appears that Soviet reliance on foreign imports (though it was undoubtedly not intended at the outset to last twenty years, as Philip Hanson ably argues)[26] has inhibited the growth of indigenous Soviet research and development in the newer branches of chemistry.

As a result, the Soviets' own efforts, even the best ones, still lag well behind the world level. Take, for example, a project completed in Byelorussia in 1974, a joint Soviet-East German plant to produce polyethylene under high pressure. The plant embodies major advances over previous high-pressure technology, and was awarded a State Prize in 1976, but it is currently being eclipsed by Western developments that make it feasible to produce polyethylene more productively under low pressure. If this case is representative (and interviews with British and

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[24]Central Intelligence Agency, *Soviet Chemical Equipment Purchases from the West: Impact on Production and Foreign Trade,* ER 78-10554, Washington, D.C., October 1978, p. 8.

[25]V. M. Bushuev, *Khimicheskaia industriia v svete reshenii XXIVogo s"ezda KPSS*, Moscow, 1974, pp. 30-31, cited in Philip Hanson, "Soviet Strategies and Policy Implementation in the Import of Chemical Technology from the West, 1958-1978," California Seminar on Arms Control and Foreign Policy, Discussion Paper No. 92, Santa Monica, California, March 1981.

[26]Ibid.

Table 1

SOVIET IMPORTS OF CHEMICAL EQUIPMENT

	Value (in thousands of rubles)								
Exports	1970	1971	1972	1973	1974	1975	1976	1977	1978
Total	217,955	240,438	374,809	429,740	473,745	637,975	1,132,413	1,722,314	1,743,522
From Developed West	83,524	135,573	224,462	239,985	256,534	362,111	814,569	1,364,223	1,318,535
F.R.G.	15,202	30,309	63,825	75,872	88,004	142,236	194,754	274,022	239,533
U.K.	13,769	10,356	15,903	24,292	19,386	37,112	78,450	38,747	47,690
U.S.A.	1,480	431	5,319	7,386	8,141	29,837	143,762	112,839	42,669
	Shares (in percent)								
DW of Total	38.3	56.4	59.9	55.8	54.2	56.8	71.9	79.2	75.6
FRG of DW	18.2	22.4	28.4	31.6	34.3	39.3	23.9	20.1	18.2
U.K. of DW	16.5	7.6	7.1	10.1	7.6	10.2	9.6	2.8	3.6
U.S. of DW	1.8	0.3	2.4	3.1	3.2	8.2	17.6	8.3	3.2

SOURCE: Soviet trade handbook—*Vneshniaia torgovlia SSSR*, 1970-1978.

German businessmen in chemical engineering indicate that it is),[27] then we may conclude that technology transfer in their chemical industry, even after twenty years, has not by itself been enough to give the Soviet Union an independent innovative capability that can support the further advance of their industry. Indeed, technology transfer may have retarded the growth of Soviet capabilities. Only further imports, as things appear now, will enable the advanced sector of the chemical industry to continue progressing at its present rate.

The Automotive Industry

The contribution of foreign technology to the Soviet automotive industry is another story. Westerners who have written on this subject do not agree among themselves on the precise extent to which that industry is dependent on Western technology, but two points seem clear:[28] First, by the time it began its most recent round of purchases (with the Fiat contract in 1966), the Soviet Union already possessed a well-established and vigorous automotive industry of its own (the descendant, to be sure, of Western technology imported before World War II) particularly skilled in the manufacture of trucks; and second, in the most recent deals, Soviet engineers have shown the ability to combine their skills with those of Westerners. The case of the Kama River truck complex is worth citing at length, because of the widespread impression recently conveyed by Western media that the West made a crucial contribution to Soviet military technology in that case:

> Truck production has long been the forte of the Soviet motor vehicle industry. Soviet management of the Kama project in the 1970s reflects great experience and readiness in truck manufacture. The 8-ton KamAZ truck is entirely of Soviet design. The USSR prepared the overall plan of the project and designed and built the shops.

[27]Philip Hanson and Malcolm R. Hill, "Soviet Assimilation of Western Technology: A Survey of U.K. Exporters' Experience," in U.S. Congress, Joint Economic Committee, *Soviet Economy in a Time of Change,* Vol. 1, U.S. Government Printing Office, Washington, D.C., 1979, pp. 582-604.

[28]See, for example, George D. Holliday, "Western Technology Transfer to the Soviet Union, 1928-37 and 1966-75, with a Case Study in the Transfer of Automotive Technology," Ph.D. Dissertation, George Washington University, 1978. Holliday concludes that the Soviet policy of selective imports in the automotive sector stems from their fundamental inability to stay abreast of Western technological developments.

> Only specialized production machinery and layout plans for its employment were purchased abroad. . . .
>
> The experience of the KamAZ foundry provided an insight into Soviet ability to manage the design of a major production shop. The KamAZ foundry is a complex of four separate foundries. The Soviets engaged Pullman-Swindell to design three of the four—cast iron, steel, and nonferrous metals. The Soviets designed and built the fourth, the precision casting foundry, themselves. . . .
>
> Pullman-Swindell was not given a free hand. A rotating team of 70 Soviet engineers was assigned to the United States to oversee the engineering and design work. . . .
>
> The Soviets maintained control of the installation and startup phases of the KamAZ foundry just as they did with the other shops. . . .[29]

In the automotive industry, then, the result of Western technology transfer has not been dependence but a reinforcement of already considerable Soviet skills, particularly as a result of the Soviets' insistence on receiving elaborate training as part of the Pullman package. Western observers may disagree over whether in this case the West transferred to the Soviets anything the latter could not have developed eventually by themselves; undoubtedly the most valuable commodity transferred was a saving of time. Nevertheless, the primary reason that the Soviets were able to take such good advantage of Western technology was that they started from a level that was already high.

The Computer Industry

The case of computers, finally, illustrates still another pattern of interaction between imported Western technology and native Soviet capabilities. In this field as in the others, there was a relatively sudden high-level decision to upgrade the priority of the computer industry, after more than a decade of comparative neglect.[30] In this case the Soviets did not have the option of resorting to massive imports of manufacturing plant from the West. But access to Western technology was not lacking for all that, and according to the leading Western authority on the subject, Soviet progress in computers in the last fifteen years has been essentially a recapitulation of Western experience.[31]

A recapitulation, but not a copy. The Soviet radio, electronics, and instrumentation industries have made impressive progress in computers in the last fifteen years. For example, though the two "Ryad" families of computers (developed jointly with several East European countries) rely heavily on the IBM 360 and 370 series, they are not "reverse engineering" of the IBM, but "effective functional duplications." The difference is important:

> The architecture, instruction set, and data channel interfaces are the same, permitting the use of IBM software and interchange at the CPU or major subsystem level with relatively little difficulty. Although there is no detailed copying of electrical or mechanical components or manufacturing techniques, the CMEA countries have

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[29]Central Intelligence Agency, National Foreign Assessment Center, *Role of Foreign Technology in the Development of the Motor Vehicle Industry,* Washington, D.C., October 1979.

[30]For a candid description of Soviet activity in first-generation computers up to the mid-1950s, at which time the level of Soviet technology was roughly on a par with that of the United States, see the memoirs of the late Soviet mathematician M. A. Lavrent'ev in *Ekonomika i Organizatsiia Promyshlennogo Proizvodstva,* Vol. 10, 1979. Lavrent'ev also allows himself some speculation on the reasons why the Soviets subsequently fell behind.

[31]See Seymour E. Goodman, "Soviet Computing and Technology Transfer: An Overview," *World Politics,* Vol. 31, No. 4, July 1979, pp. 539-570. The article contains extensive references to more detailed studies. The reader should consult in particular an excellent survey of the Ryad series, in N. C. Davis and S. E. Goodman, "The Soviet Bloc's Unified System of Computers," *ACM Computing Surveys,* June 1978, pp. 93-122.

> achieved some limited compatibility of media, permitting the exchange of cards, magnetic tapes, and disk packs.
>
> It is important not to underestimate the achievements of the CEMA computer scientists. . . .[32]

In the case of computers, then, instead of accepting dependence on the West the Soviets have made a serious effort to develop their own independent capabilities (in this case, together with their CMEA partners).

Nevertheless, the Soviets remain behind; indeed, after fifteen years of hard efforts, their lag behind the world leaders in computer technology has not closed.[33] Moreover, as computer technology takes its next turn into the future, toward smaller, custom designed, dedicated systems, the Soviet computer industry is encountering additional difficulties. However, the Soviets' problems do not appear to be due primarily to Western export controls as such (indeed, the Soviets have demonstrated that they can acquire hardware and software by covert means). Rather, the most serious obstacles—and these are likely to loom ever larger in the future—come from within: poor working relations between Soviet producers and users; failure of the manufacturing ministries to treat a computer as a package, with provision for service, supply with software, peripherals, etc.; and the slowness of users to adapt to computer operations. Though direct Western example and instruction have been available to them, the Soviets have apparently not gained from it the capacity for independent advances; in fact, in several respects they have repeated some Western mistakes along the way.

CONCLUSIONS

The three cases briefly sketched here suggest several important points about the contribution of technology transfer to Soviet capabilities for self-generated innovation. First, we may be sure that imported technology plays not one, but a variety of roles, depending on the specific problems of each industry; and therefore the consequences of interaction between the two are equally varied. In the chemical and the automotive cases, the resort to imported equipment was essentially a "quick fix," intended to provide rapidly an advanced mass-production capability while the Soviets' own technology caught up. However, the ability of Soviet scientists and engineers to use foreign technology to advance on their own appears to depend on the level they had already reached before the massive arrival of foreign imports. In the automotive industry they had already developed considerable skill, and the result was a synthesis. In the chemical industry they had not, and the apparent result has been stagnation and continued dependence.

Hence a seemingly paradoxical theorem: The greater the Soviets' existing level of skill in a particular industry, the more they are able to profit from technology transfer, and the harder it is to prevent them from doing so. The corollary is that the Soviets' ability to profit from technology transfer can be expected to increase over time *provided* that the Soviets have not handicapped their own innovators (as in the chemical industry) through an excessive reliance on foreign suppliers. Such increasing capabilities are precisely what Goodman predicts for the Soviet computer industry in the 1980s.

In conclusion, the usual course of events is that, from dependence, a receiving country

[32]Goodman, op. cit., p. 556.

[33]See R. Judy, "The Case of Computer Technology," in S. Wasowski, ed., *East-West Trade and the Technology Gap*, Prager, New York, 1970, pp. 43-71. Judy covers Soviet developments up to 1968. For further description bringing the account up to 1973, see Martin Cave, "Computer Technology," in Amann, Cooper, and Davies, op. cit., pp. 377-406.

moves toward complementarity, which is the mature and final stage of international exchange of technology. The classic example is Japan, but since the beginning of the industrial revolution there have been others, including France and Germany in the early nineteenth century. How quickly that stage is reached, however—in fact whether it will be reached at all in the Soviet case—depends much more on the limitations imposed by the environment and policies of the recipient than by the policies of the provider.

The chemical industry provides one kind of illustration, for here the main obstacles appear to be: competition from the military for some of the major skills required, relatively low priority and inefficiency of construction in the chemical industry, and possibly also the fact that the Soviets have considered it relatively safe to allow themselves to be dependent on the West in this area, in view of the wide range of suppliers available, the relatively slack construction capacity in the West, and the willingness (until recently) of Western suppliers to accept buy-back arrangements.

The computer industry illustrates the same propositions in a different way: The obstacles now standing in the way of the Soviet computer development may be due as much to Soviet unwillingness to be directly dependent on Western technology (in high-priority areas) as to Western unwillingness to export to them; and their ability to profit from the transfers of knowledge they receive in this field is limited more by producer-user relations at home than by the unavailability of training from the West.

To sum up the major arguments of this section: twenty years of Western and Soviet studies of innovation show that the relationship between "need-pull" and "discovery-push" is complex, varying widely from one industry to another and from one period to the next. In all cases, however, productive synthesis of the two depends on some combination of effective supply and demand and also on the quality of the transmission mechanisms, both formal and informal, that connect them. It follows that the contribution of foreign technology to the Soviets' innovative capabilities will also vary from case to case, depending on what native skills already exist in the particular industry concerned, what weaknesses foreign technology is being used to remedy or compensate for, and what part of the Soviet R&D network happens to be receptive to change. In some cases it is the finished product, embodied in a turnkey factory, that is the main contribution of the transfer. In other cases it is an abstract concept, such as the organization of an after-sale service network. The one general proposition that seems to apply across the board is that as time goes by the importance of the latter, "higher-order" type of transfer will grow, and that as the Soviets' skills in the management of technological innovation increase, their ability to profit from such high-order transfers or skills will increase also.

If that is true, then the United States should pay particular close attention to the efforts that the Soviets are making to improve the management of technological innovation as a whole. This will be the subject of the next four sections. We should bear two questions in mind: (1) To what extent is any given reform the result of Western inspiration, transferred through active mechanisms that might be controlled by Western policy? (2) To what extent does any given reform require Western technology to succeed, or make the Soviets more dependent (or less) on imported technology?

III. MINISTRY-WIDE REFORM: THE CASE OF THE MINISTRY OF ELECTRICAL EQUIPMENT

Much of what is new in Soviet R&D policy in the last ten years stems from a single watershed decree, issued in 1968 by the USSR Council of Ministers and the Central Committee of the Communist Party.[1] Among its many provisions, it announced a ministry-wide experiment in the management of technological innovation. The ministry selected for the first experiment was the Ministry of Electrical Equipment (*Ministerstvo elektrotekhnicheskoi promyshlennosti*).[2] The choice of this ministry is especially interesting because, as the country's principal manufacturer of electrical machinery, it handles a wide range of output, from the world's largest turbogenerators to small electrical motors and appliances, including consumer goods like vacuum cleaners and electric samovars. The ministry also exhibits a great range in the vigor and quality of technological innovation. Broadly speaking, at the large-generator end of its line, it is innovative and highly competent. In the manufacture of turbogenerators, for example, it rivals General Electric and other leading Western firms as a vigorous competitor in world markets. In contrast, at the small end of its product line, particularly in the consumer goods sector, the ministry is undistinguished.

In the opinion of American specialists who have visited the ministry's manufacturing and research facilities, the last decade has been one of major progress in large equipment. Large generators, in particular have undergone major improvements in reliability and durability, as well as increases in output capacity. The Russians are not yet world leaders in this branch of technology, but they are improving rapidly. Consequently, large electrical equipment represents a good example of the kind of crucial, advanced civilian technology which, this report argues, is both the main precondition and the main obstacle to Russia's future strength as a great power. It is important to know how to account for the Soviet advances in this technology in the last ten years. What share of the credit should go to the ministry's 1969 reform? And how much to the contribution of Western technology, whether directly in the form of products and skills, or indirectly as an inspiration for the reform itself or some of its underlying ideas?

The first Soviet assessments of the reform, based on a decade of experience, are now beginning to appear, giving us the basis for a preliminary appraisal. The difficulty, as we shall see, is that the Soviet evaluations are based on highly aggregated and frequently ambiguous data, and we must be cautious in interpreting them. Nevertheless, we shall be able to venture some conclusions about the likely overall effectiveness of the reform, as well as suggest further lines of inquiry.

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[1]TsK KPSS, 1968 decree, op. cit. The decree specifically refers to defense needs as one of the motivations for the series of reforms it announces.

[2]On a visit to the State Committee on Science and Technology in Moscow in January 1979, we asked I. D. Ivanov, a Soviet expert on Soviet technology policy, what had prompted the choice of Minelektrotekhprom as the "lead-off" ministry for the 1969 reform. The Russians present laughed, and Ivanov answered, "Antonov [Minister A. Antonov, since promoted to Deputy Prime Minister] was the only one who was willing to give it a try."

Another, perhaps more meaningful clue comes from a speech by Academician V. I. Popkov, delivering the 1977 annual report of the USSR Academy of Sciences, Division of Physical and Engineering Problems of Energy ("O sostoianii issledovanii po elektrofizike i elektrotekhnike," *Vestnik Akademii Nauk,* No. 7, 1977, p. 6.): "A number of specialists have come to hold the view that the development of electrical engineering as a science is complete, that there are no more new, promising directions of research in that field. Little attention is being given to the modernization and re-equipment of existing laboratories, research institutes and institutions of higher education, or to the development of problem-oriented research there."

We begin with a description of the experiment.[3] It consists of four sets of changes: a new incentive system, a new basis for funding R&D and start-up costs, changes in the planning system for new technology, and, as a later addition, a restructuring of the organization for R&D. As we shall see, the electrical equipment experiment is aimed at all three of the ailments described at the beginning of Sec. II. It is the most balanced and comprehensive (at least in its aims) of all the reforms described in this report.

DETAILS OF THE REFORM

Changes in the Planning System

Full-cycle planning. For each major project, a lead institute is now appointed to cover every step in the full R&D cycle, from exploratory research to full implementation of a new product or process. It issues orders (*zakazynariady*) to the actual performers for each step.

Planning on the basis of a triennial rating system. Every item of output, whether new or old, undergoes a rating every three years, on the basis of which it is placed in one of three categories: highest (symbolized by the Quality Mark), first, and second quality. Among the criteria: whether the item in question meets the highest world standard, and whether it ensures a high economic return.

Items rated as "second" quality are placed on a list for removal from production and replacement by new products or processes.

Whole enterprises are also rated in the same way, and an obsolete plant is scheduled for modernization.[4]

A new system of targets. Alongside their traditional performance targets, enterprises must now also show targeted improvements in the levels of:

- volume of production based on new products or processes
- labor intensiveness, expressed as the number of workers who could theoretically be released as a result of technological innovation
- production costs (*sebestoimst'*)
- annual economic return (*effekt*)
- proportion of new output awarded the Quality Mark

Changes in the Incentive System

A new basis for the bonus system. Recent changes in the incentive system have two aims: (1) to get away from the practice of giving all divisions the same automatic bonus at the end of each production period, regardless of whether they actually contributed anything to innovation in production (a practice called leveling, or *uravnilovka*); (2) to give research and design institutes a greater share in the returns from their work. The new system has, in principle, the following features:

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[3]Except where otherwise noted, this description comes from V. E. Astaf'ev, L. Ia. Povolotskii, and V. P. Khaikin, *Ekonomicheskii mekhanizm uskoreniia nauchno-tekhnicheskogo progress* (opyt i problemy), "Ekonomika," Moscow, 1977.

[4]A. Dzhanoian (Director of Soiuzelektrotekhnika), "Tekhnologiia i ekonomika," *Sotsialisticheskaia Industriia*, December 21, 1977.

- It is tied to the economic return actually achieved in series production of new products or processes; and it is not paid before series production actually reaches planned output levels.
- It is also tied to the proportion of new production that qualifies for the Quality Mark.
- And while during the first year bonuses are awarded for attaining any production at all, during the two subsequent years the main reward is given for attaining *increases* in production. Then, at the end of the third year, the product or process in question is rated again.

A fatter bonus fund (combined with the threat of a leaner one in case of bad performance). Products or processes rated in the "second category" beyond the deadline for removal from production are penalized by a cut in their wholesale price, thus lessening the income of the producing enterprise.

For products that are awarded the Quality Mark, special add-ons to the wholesale price are granted to provide the producer with a greater profit and a fatter bonus fund.

A New System for Funding R&D and Start-Up

The most important source of funding for R&D and start-up of new output or processes is now a "single" fund formed from a percentage of the planned profit of each major unit in the ministry.

Among the advantages claimed for this system: It makes possible a centralized, programmed management of R&D and targeting toward the most promising R&D possibilities; and it makes the system of full-cycle planning more than a paper system

Organizational Restructuring

This is the most recent part of the reform, for it was fully launched only in 1975. It consists of the following main features.

Most of the ministry's activity is now organized under 14 USSR-level "industrial associations." One level down in the hierarchy, some 60 percent of the ministry's output is organized around "production associations."[5]

In addition, two-thirds of the ministry's research institutes and design bureaus have been internally restructured around a single specialty, and each one subordinated to a production association or a large enterprise.[6]

Finally, 18 large scientific and technological "centers" have been organized around the most important long-term directions of research. Most of the basic research of the ministry is now concentrated in these centers.

So far, there has been very little discussion in the Soviet literature of how these changes have worked out in practice in the electrical equipment industry, undoubtedly because they are too recent.

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[5]This pattern of organization is similar to the one adopted throughout the economy in the 1970s. In the Ministry of Electrical Engineering, however, NPOs have not been as prominent an organizational device as in some other ministries. For detailed treatment of NPOs, see below.

[6]Another source says that only half of the ministry's institutes and design bureaus are so subordinated. See A. Antonov (then Minister of Electrical Engineering), "Ekonomika tekhnicheskogo progressa," *Pravda*, September 5, 1979.

ASSESSING THE RESULTS OF THE REFORM (I)

In this section we shall focus on two of the most important aspects of the experiment: the Single Fund for R&D and the rating system for Quality and Innovation.

The principal feature of the new funding system is the creation of a Single Fund for the Development of Science and Technology (*Edinyi Fond Razvitiia Nauki i Tekhniki*—EFRNT). As we shall see, the Single Fund does not cover more than half of the ministry's R&D expenses,[7] and therefore it is not actually "single" at all, but compared to earlier systems it is intended to be a sizable step toward the creation of a centralized, targeted, project-based mechanism of funding.

The Single Fund actually represents a second round of reform. In research and design, the traditional Soviet method (which still accounts for about half of all Soviet funding for ministry R&D nationwide) is to fund each research institute or design bureau as a block. As all block funding systems typically do, this system tends to lead to allocation by seniority and log-rolling within the institute, and makes it difficult to apply external performance review or rapid changes in external priorities. Under block funding, the Soviet institutes tend to be indifferent to the practical applications of their work. Consequently, for some years the Soviets have been engaged in searching for a system of financing R&D that will make institutes responsive without at the same time over-directing them. In 1961 the traditional system was replaced in some ministries by a dual one. Top-priority projects continued to be funded from the central budget. But ministry-level projects were supported from a fund set as a fixed percentage of the ministry's production costs (*sebestoimost'*).[8] This was the arrangement in effect in the Ministry of Electrical Equipment from 1965 to 1969.

Several things were wrong with it. First, it was wrong conceptually, since successful technological innovation, by reducing production costs, would also reduce the R&D fund. Second, the two-tiered system was awkward, since different parts of the same project sometimes ended up being funded from independent sources (thus reducing leverage for central, coordinated targeting). Finally, any unspent remainder had to be returned to the treasury at the end of each year, an awkward feature for any project lasting longer than one year.

Hence the creation of the Single Fund in 1969. It differs from the previous system in all three of the respects just mentioned: It carries over from year to year; it includes (in principle) *all* major R&D projects, both top-level and ministry-level; and it is calculated as a share of profits rather than production cost. It is allocated to the performers project by project, through an instrument that is, in effect, a contract with the legal force of a plan-mandated supply order. In principle, then, the Single Fund is a flexible instrument for the management of research.

The R&D fund was initially calculated as a flat 13 percent deduction from profit.[9] Unfortunately, basing R&D funding directly on profit proved to be unstable, because in 1973 Minelektrotekhprom went through a centrally mandated downward price reform that cut its income by 2.5 billion rubles.[10] This in turn required major rejuggling of planned profit levels and of the percentage to be deducted for R&D. To maintain a stable R&D budget, the ministry

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[7]K. Kedrova, E. Vasil'eva, L. Panova, "Ob ispol'zovanii edinogo fonda razvitiia nauki i tekhniki," *Planovoe Khoziaistvo*, No. 6, 1977, pp. 131-135. Soviet sources appear to conflict on this point: According to the minister, the Single Fund means that the ministry no longer receives R&D funding from the state central budget (Antonov, op. cit. (1979)). The explanation seems to be that the other half of the ministry's R&D funding comes from "contracts" (presumably from other ministries and agencies). These contracts (*khozdogovory*) are discussed in Astaf'ev, Povolotskii, and Khaikin, op. cit., pp. 63, 220, and 222.

[8]This is actually a revival of a system used in the 1930s. See Parrott, op. cit. (1976).

[9]Profit stems from two principal sources: either lower production costs *or* a price increase (granted to innovations which meet the highest quality category).

[10]Astaf'ev, Povolotskii, and Khaikin, op. cit., pp. 18 and 55.

resorted to setting a different deduction rate each year, which varied as follows:[11]

1969	13.0
1970	13.4
1971	16.8
1972	16.9
1973	32.6
1974	21.0
1975	27.0

Thanks to this annual juggling, the funding for R&D has grown at a more or less steady rate, nearly doubling between 1969 and 1975.[12] (See Figure 1.)

There is considerable complaint in the Soviet literature, however, with what the Single Fund does *not* cover. Only a small fraction of it is devoted to financing equipment and start-up costs of new technology. The situation apparently reached a crisis in 1971, when only 10 percent of the Single Fund went to start-up costs (90 percent went to research and design). Since then, there has been only slight improvement: As of 1975 enterprises still received less than 15 percent of the Single Fund for start-up.[13] This fact defeats much of the purpose of the Single Fund and it implies that full-cycle management is not being achieved. Enterprise managers who have the assignment of launching production of a new product or process have no choice but to assign the costs to the production costs of the product (*sebestoimost'*), lowering their profit and hence their overall bonuses. And if they cannot raise the capital (credit not being a major instrument of financing, as a rule), then series production cannot be launched at all. Given these circumstances, it is not surprising to learn that 90 percent of new output in the ministry (by volume) is launched through the construction of new plants or major reconstruction of old plants (which is financed through centrally allocated investment funds), rather than conversion or upgrading of working production lines.[14] What is puzzling is to read that since the reform began there has been a virtual disappearance of R&D projects "left on the shelf," that is, successfully executed by the researchers and designers but not introduced into production. How can this be, if at the same time the ministry is underinvesting in development and testing? We should probably be prepared to find a good deal of pro forma, small-batch, pseudo-innovation in the industry's older enterprises, particularly outside the large-equipment area, designed to satisfy the enterprises' new target indicators for innovation.

ASSESSING THE RESULTS OF THE REFORM (II): THE RATING SYSTEM

The centerpiece of the ministry's new planning and incentive system is a rating procedure to determine the quality and "technical and economic level" of every product produced. According to the minister, in 1978 43.5 percent of the ministry's total output qualified for the highest

[11] Kedrova, Vasil'eva, and Panova, op. cit.

[12] Astaf'ev, Povolotskii, and Khaikin, op. cit., p. 55. On the whole, Soviet observers seem satisfied with the overall figures: There has been an average 9 percent annual increase in the number of research and design projects executed, at a total cost that rose faster than other production costs but less fast than the economic return the R&D is reckoned to have contributed.

[13] Kedrova, Vasil'eva, and Panova, op. cit., p. 132.

[14] Though the wording of the Russian source is not specific on this point, it seems to mean 90 percent of the ruble value of new output, not 90 percent of the number of new products and processes. This suggests that a great deal of *small-batch* innovation may be going on at older enterprises, and this would not require very much start-up money.

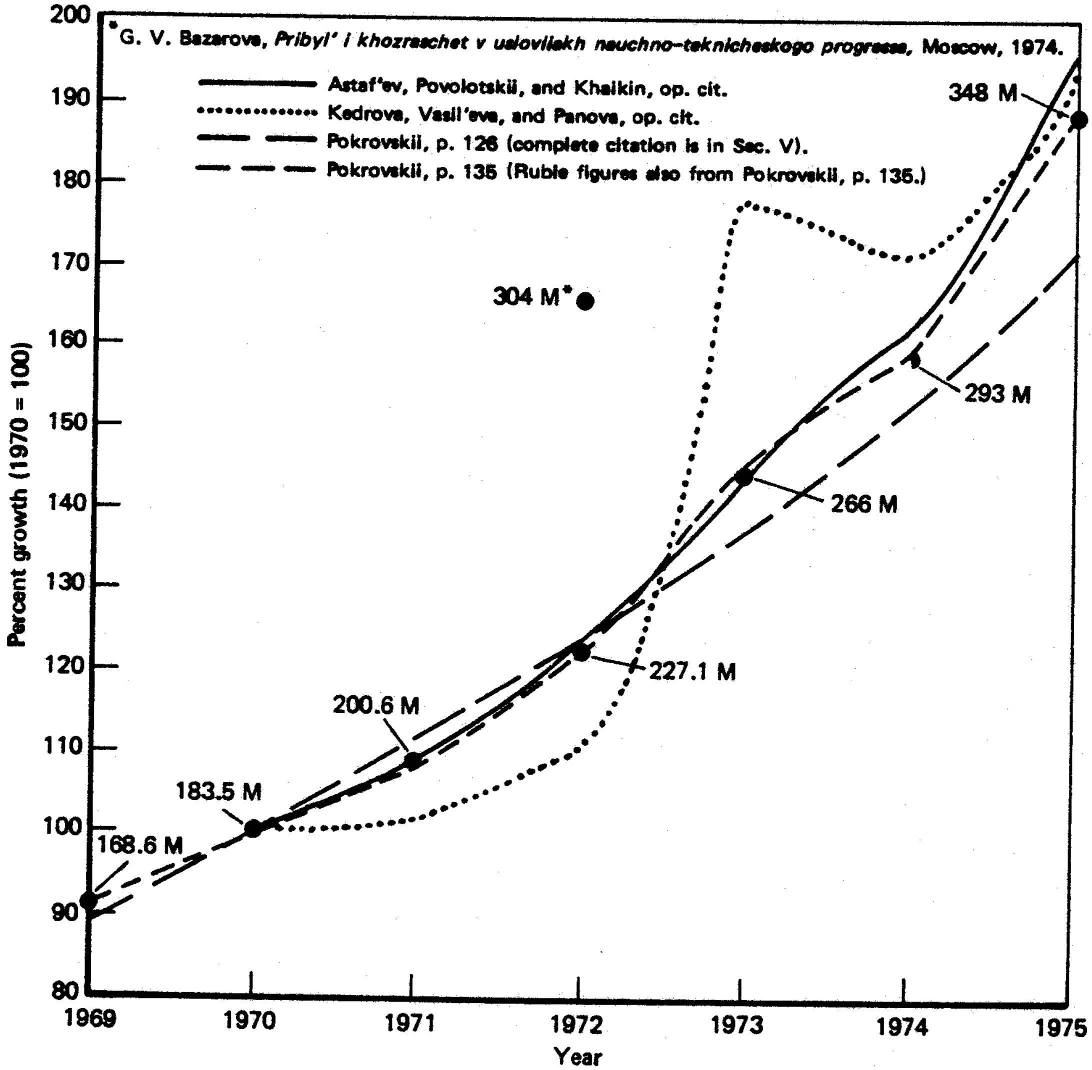

Fig. 1—Evolution of the Single Fund in the Ministry of Electrical Equipment: Various Soviet Estimates, 1969-1975

of the three categories of quality, that is, was awarded the Quality Mark,[15] up from 12.2 percent in 1968.[16] But what lies behind these statistics? In practice, the operation of the rating system depends on a number of difficult questions: (1) Who performs the rating? (2) At what stage of the R&D process is it performed? (3) What prevents the raters from falling behind? (4) What prevents them from debasing the standards? (5) Will they not apply engineers' standards rather than economists', so that they will end up rewarding technological novelty rather than useful innovation? In the following subsections we examine what the recent Soviet literature has to say about these questions.

Who Sits on the Rating Commissions?

First, the ministry's rating system avoids the pitfall of having colleagues review one another within the closed space of a single institute or enterprise.[17] The ratings are performed by State Rating Commissions (*Gosudarstvennye Attestatsionnye Komissii*, or GAKs), composed of representatives of the principal customers for the product under review, as well as representatives from various state agencies and the Ministry of Electrical Equipment itself.[18] Given interagency committees with such diverse membership, one can anticipate problems of overload and lag, for they are called upon to rate 2000 or 3000 new products each year, and the review must be repeated every three years.[19] Consequently, the danger is pro forma review, especially since the customer representatives, far from having leverage over the Ministry of Electrical Equipment, probably have every incentive not to give offense, lest their supplies suffer.

At What Stage of the R&D Cycle Does the Rating Occur?

Clearly, a rating system of this kind is subject to one inherent tradeoff: Perform it too early in the R&D cycle, and it misses the important subsequent stages of development and engineering; perform it too late, and it fails to prevent expensive mistakes and mediocre designs. It is not clear what the ministry's solution was prior to 1974; but it was apparently plagued with delays and other problems. Accordingly, since 1975, the ministry has used a dual system: Products executed on a one-time basis (including one-of-a-kind pieces) are reviewed early, at the stage of the technical documentation, before the item is actually manufactured. Items intended for series production, on the other hand, are rated on the basis of models drawn from the production line. This system makes the ministry's aggregate statistics on product quality virtually meaningless, for each quality category includes two very different types of products: a large number of custom-made items that are reviewed on paper, and a small number of mass-production items that are reviewed (as the Russians say) "in the metal." Yet presumably

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[15]Antonov, op. cit. (1979).

[16]Astaf'ev, Povolotskii, and Khaikin, op. cit., p. 96. Note that the figure increased by only 1.9 percentage points from 1975 to 1978, in contrast with a jump of 25.7 percentage points from 1970-1973.

[17]For a description of a rating system for researchers' salaries with this problem, see two articles in *Literaturnaia Gazeta*, No. 28, July 12, 1978: G. Lakhtin, "Ne stanem obol'shchat'sia," and V. Kharin, "No ne budem i skeptikami!," p. 11.

[18]Astaf'ev, Povolotskii, and Khaikin, op. cit., p. 94. In particular, the list includes representatives of the State Committee on Standards; and from within the ministry itself, members of the leading research institutes, the ministry's bureau for standards, the *glavk* whose product is being reviewed, and the technical review division of the enterprise concerned.

[19]This rough figure can be inferred from the fact that in 1975 about 1500 new products of the "highest" quality level were introduced into series production. (Astaf'ev, Povolotskii, and Khaikin, op. cit., p. 15.)

the criteria and incentives applying to each are very different. One would like to know the answers to the following questions:

- Is there a tendency to be lenient in passing on one-time-only items? One might think so, since they will be produced in only a small number of units. On the other hand, since they are reviewed at the documentation stage, it is relatively easy to reject them. The existing statistics do not enable us to tell.
- Is there a tendency to be lenient in rating mass-production items? Again, one might think so, because by the time the item comes up for review, an entire production line has been created, customers are presumably waiting, bonuses are at stake, etc. But this question too must remain unanswered for the time being.

What Standards Are Used, and What Prevents Them from Becoming Watered Down?

The criteria used in the rating system are chosen by the "head" design institutes of the ministry (subject to approval by customer organizations), based on the general principle of comparison to the best known technology in the same area, commonly the best foreign product. But choosing and using such analogs as a basis for comparison assumes highly qualified raters and good access to the latest foreign information, compatible criteria, and sufficient detail to make the rating meaningful. The criteria appear to be heavily biased toward engineering and technological criteria, not economic ones—a further invitation to goldplating.[20]

By its very conception, the rating system pioneered by Minelektrotekhprom is an attempt to substitute for a buyer's market by synthesizing one around a committee table. Like any administrative substitute for market pressure, it is vulnerable to some well-known standard problems: overload and inappropriate indicators and incentives, leading to delays, debasement of standards, and pro forma performance. Judging from the material we have seen, there are tendencies in that direction in the ministry's system, but the facts examined so far are not adequate to determine whether it has resisted them or succumbed. The one thing that one can say with fair assurance from the structure of the rating system is that it tends to apply the standards of engineers rather than those of economists, except insofar as cost considerations are transmitted indirectly through the foreign analogs used by the raters.

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Ten years after it first began, the experiment in the Ministry of Electrical Engineering is officially considered to be enough of a success that it has been extended to 14 ministries in all, beginning with the Ministry of Heavy Machine-Building in 1974.[21] But how influential has the reform actually been? Joint work between Americans and Soviets in the area of turbogenerators and other large equipment suggests that the ministry performs considerably better at that end of its output range than in the area of smaller equipment. There may be some simple reasons for this, which have little to do with the 1969 reform. Consider some of the outstanding features bearing on technological innovation in large electrical equipment: (1) Each unit is essentially custom-designed, and output is confined to a few large units; (2) innovation is incremental, driven chiefly by increases in machine size; (3) for most of the ministry's output of such large equipment, there is a single, large, influential customer; (4) the

[20]The information for this section is drawn from Astaf'ev, Povolotskii, and Khaikin, op. cit., p. 97.

[21]The reform now applies to the chemical and light-industry ministries, commercial shipping, and machine-building in the following areas: heavy machinery, power-generation, agricultural, chemical, tractors, and machine tools.

Soviets have a long history of excellence in the manufacture of large generators, as a result of which there exist three or four major manufacturers with well integrated research and design capabilities attached to the plants; (5) the manufacturers have elaborate test facilities; (6) there is an international community with considerable contact and communication, and the Soviet manufacturers have an active export program; (7) there is some competition among several Soviet manufacturers. All these features suggest that the reform in the ministry, taken alone, may not be a very important explanation for its superior performance in large equipment; indeed, one possible interpretation of the reform is that it is an attempt to extend to the more backward areas of the ministry some of the formulas that have worked well for the leading divisions. Fortunately, it will soon be possible to develop better answers to these questions, for the field of heavy electrical equipment is one of the topics of investigation under the Joint U.S.-Soviet Working Group on Technology and Innovation, under the auspices of the National Science Foundation. This is an especially important subject for further investigation, because the electrical-equipment reform is now the official model for management of technological innovation in over half of the industrial ministries of the Soviet Union; in addition the ministry itself is heavily involved in R&D for Soviet alternatives to oil, notably long distance power transmission, hydropower, and coal combustion. Consequently, the recent experience of the ministry is an important key.

IV. STRENGTHENING FACILITIES FOR DEVELOPMENT AND EXPERIMENTAL PRODUCTION

One of the most serious gaps in the Soviet RD&D cycle, in the Soviets' eyes, is the lack of suitable facilities for testing and pilot production of new products and processes—what the Russians call (although there are many variations in the exact terms used) *opytno-eksperimental'nye bazy.*[1] This broad term covers two main types of facilities—those attached to research or design institutes, and those associated with industrial enterprises. In 1975 there were 3000 of the first type (including those attached to educational institutions), employing 650,000 people, and over 5000 of the second type, with 1,400,000 people.[2] Within these two groups there is a very wide range, from the small laboratory to the large, semi-independent enterprise. To illustrate, take a recent listing of the so-called "test" facilities of the Ukrainian Academy of Sciences:[3]

- 4 factories (*zavody*)
- 29 facilities for pilot production (*opytnye proizvodstva*)
- 18 offices for design and engineering development (*konstruktorsko-tekhnicheskie biuro*)

This is clearly a very mixed group. As we review recent Soviet discussion of these facilities, therefore, we should keep in mind that the Soviets themselves are far from clear or consistent about the scope or boundaries of the problem.[4]

Soviet observers are unanimously convinced of two things about these facilities: There are too few of them, and they are misused—subverted, in fact—by the parent ministries.[5] Both problems are of long standing. Ten years ago, a massive report by the OECD on R&D in the Soviet Union, based to a considerable extent on Soviet sources, concluded that the greatest single obstacle to technological innovation in the Soviet Union was the ministries' lack of attention to development facilities.[6] Has there been any improvement since? One of the principal reforms of the last ten years, at least on paper, has been to invest more in pilot facilities and to combat the subversion of them by the ministerial bureaucracies. As we shall see, the Soviet verdict is that neither approach has been particularly successful so far.

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[1]The exact type of operation covered at this phase varies from one source to the next, running from the manufacture of a small number of prototypes or trial batches (*narabotki*) to demonstration, pre-series production or LRIP (corresponding, we think, to what the Russians call *pusko-naladochnye raboty*). Broadly speaking, what is involved here is the sequence of operations between design and full-scale series production.

[2]G. M. Glagoleva, "Faktor vremeni v tekhnologicheskom osvoenii nauchnykh otkrytii i razrabotok," *Planovoe Khoziaistvo,* No. 10, 1977a, p. 106. In addition there are so-called *opytno-eksperimental'nye organizatsii* that accounted for 0.76 percent of the overall numbers of all enterprise personnel in 1975: V. I. Kushlin, *Uskorenie vnedreniia nauchnykh dostizhenii v proizvodstvo,* "Ekonomika," Moscow, 1976, p. 87.

[3]V. Trefilov (Vice-President of the Ukrainian Academy of Sciences), "Kon veier vnedreniia," *Izvestiia,* February 19, 1977.

[4]A Soviet specialist on technology policy, G. M. Glagoleva, discusses problems of classification in *Tekhnologicheskoe osvoenie nauchnykh otkrytii i razrabotok,* "Ekonomika," Moscow, 1977b, pp. 54-55.

[5]This has been a chronic complaint in Soviet technology policy since the 1930s. However, that may say more about the critical bias of the Soviet press and the self-serving complaints of the engineers than about the state of the facilities themselves or the need for them.

[6]E. Zaleski et al., op. cit. The report specifically mentions weaknesses of the *opytno-eksperimental'nye bazy* and their personnel (pp. 387-388), insufficient investment in them (p. 427), and the tendency to load them down with conventional series production (p. 426). There were recommendations, then as now, to shift investment from production to development (p. 398). The weaknesses of factory laboratories received particular attention (pp. 409-412). The only exception noted at the time was the machine-tool industry (p. 421).

The first approach is increased investment. During the Eighth Five-Year Plan (1965-1970), investment in development facilities attached to scientific institutes was slated for a rapid increase: The planned level for 1970 was nearly 48 percent higher than in 1965 (compared to a 32 percent increase scheduled for capital construction in science as a whole), so that by 1970 planned investment in development facilities was slated to reach 45 percent of all capital investment in science.[7] During the Ninth Five-Year Plan (1971-1975), investment in development facilities for scientific institutes was intended to rise even more rapidly: 12.9 percent per year on the average, versus 6.2 percent a year for overall capital construction in science.[8] Unfortunately, we have found no figure to indicate the absolute amounts these percentages correspond to. What the planned percentages do show, however, is the planners' intention to have test and pilot producing facilities grow faster than R&D as a whole.

But it is quite clear that the industrial ministries lagged badly in carrying out the program. According to numerous sources, the plan-fulfillment rates for construction of development and pilot-production facilities are some of the worst in the entire economy: 60 to 70 percent during the Ninth Five-Year Plan (1971-1975), compared to 90 to 95 percent for all other types of construction. There may have been some improvement during the Tenth Plan (1976-1980), for a more recent source gives a figure of 86 percent fulfillment for 1977—still a low figure, however, compared to those usually claimed.[10] The main reason appears to be the ministries' lack of commitment, for they are criticized for giving extremely low priority to development and pilot-production in their own annual investment plans.[11] A survey of 41 industrial ministries showed that less than 0.3 percent of their total capital investments went into development and pilot-production[12] (during the Ninth Plan), and only in a few instances did the figure exceed one percent.[13] Another survey of 26 industrial ministries gives an average figure of 0.4 percent.[14] In many cases the ministries' investment plans include no specific assignments (*zadaniia*) for development and pilot-production facilities.[15] Some ministries, to be sure, are doing better than others. The Ministries of the Petroleum Industry, Chemical Industry, and Ferrous Metallurgy get especially low marks.[16] The machine-tool industry has met less than 40 percent of "requirements."[17] But the Ministry of the Electronics Industry is said to have done an outstanding job. The Ministry of Chemical and Petroleum

[7]Kushlin, op. cit., p. 82. These figures presumably include institutions of higher education.

[8]S. M. Tikhomirov (Deputy Chairman, State Committee on Science and Technology), in V. A. Trapeznikov, ed., *Upravlenie i novaia tekhnika,* "Ekonomika," Moscow, 1978a, p. 9. These figures presumably include higher education institutions. Tikhomirov's figures confirm that computers and computer centers are classified as part of the *opytnaia baza.* Instrumentation and other equipment, however, belong to a separate classification. The latter rose by an average of 7.6 percent a year in the planned investment of the Ninth Plan. It is not clear from these statistics whether the investment in *opytnaia baza* is part of the figure for overall investment in science. Undoubtedly not, because otherwise we would arrive at the result that investment in *opytnaia baza* was planned to account for nearly *all* new capital investment in science during the Ninth Plan!

[9]Ibid.

[10]S. M. Tikhomirov, "Ot poiska do vnedreniia," *Pravda,* June 6, 1978b. The trouble with these figures is that they are ambiguous in what they cover: The first figure *may* cover plant-associated as well as institute-associated facilities. The second figure *appears* to cover plant-associated facilities, but may not cover institute-associated ones. The sources do not specify which is meant.

[11]It is not clear yet how the ministries' "own" investment plans differ from the figures mentioned previously.

[12]Once again, it is not clear from the statistics whether they apply to plant-associated facilities or institute-associated ones. Tikhomirov, op. cit. (1978a), p. 9.

[13]V. Pokrovskii (Chief of the Division for Economics and Organization, State Committee on Science and Technology), "Povyshenie effektivnosti ispol'zovaniia nauchno-tekhnicheskogo potentsiala," *Planovoe Khoziaistvo,* Vol. 3, 1977, p. 18.

[14]Glagoleva, op. cit. (1977b), p. 69. The period covered by the survey is not mentioned.

[15]Tikhomirov, op. cit. (1978b).

[16]Ibid.

[17]M. Bashin, "Ni shagu bez opytnoi bazy," *Pravda,* May 21, 1977.

Machine-Building gives the highest priority of any ministry to development and pilot-production: 8 percent of its total capital investment each year.[18] The overall failure of the industrial ministries to follow through on the planned investment levels is all the more striking when one considers that development facilities were given high priority in the special 1968 decree described earlier in this report, which called for a sufficient expansion of development and pilot facilities to allow all scientific discoveries or designs to be tested within one year at most. The deadline was 1972, but as many Soviet sources point out, the goal is far from met even now. Such high-level decrees as this are usually accompanied by a confidential appendix, listing in detail the specific projects to be undertaken, their completion dates, and the organizations responsible for them. Therefore, the ministries' shortcomings in meeting the 1972 target presumably represent more than a vague failure to respond, but a quite specific failure to complete specified projects.

Nevertheless, by some measures there has been improvement: In the mid-1960s, only 565,100 persons were employed in test facilities attached to enterprises, compared with 1,400,000 in 1975. Similarly, the number of such facilities more than doubled over the same period, from 2334 to over 5000, and the proportion of the "productive" industrial work force employed in pilot-production has also doubled, from 2 to 2.5 percent in 1964 to 4.4 percent in 1975.[19] Yet, if the test and pilot-production base of Soviet science and industry has increased so much in the last ten years, then why does the criticism of the Soviet literature remain as sharp as before? There are two possibilities: Either the increase is pro forma only, consisting largely of plant shops relabeled to meet the demand for paper improvements (to meet the deadline set by the 1968 decree), or the increase is real but ineffective, because the pilot-production facilities are unable to do their job. The answer is probably some combination of both.

One of the most serious difficulties in managing test- and pilot-production facilities is that they are easily subverted. Because output targets are tight, and because the incentive system is geared to reward people for current output, Soviet enterprises are both tempted and pressured to skimp on innovation and concentrate on their most immediate tasks.[20] One of the manifestations of this is a tendency to take over the institutes' development facilities and the pilot facilities of the enterprises and to turn them to the most urgent output target of the moment. The main culprit, according to the Soviet literature, is the middle link in the Soviet ministerial bureaucracy, the so-called "chief administration" (or *glavk*). Is the plan in danger of not being met? Has new planned capacity elsewhere in the system not come on line on schedule? Is some item of nonstandard equipment urgently needed? When such crises strike, the *glavk* or the Main Technical Administration of the ministry turns in desperation to the pilot plant[21] and orders it to help out.

This problem is apparently getting worse, not better, and it affects institute-based facilities as well as plant-based ones. Among the former, "no less than" 20 percent of the capacity of development facilities and pilot plants is taken over by current production assignments. But in some studies the figures can range as high as 50 percent.[22] Another indication in the same

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[18]Bashin, op. cit., quotes another survey of 25 industrial ministries, which found that they invested an average "in recent years" of 0.4 percent of their total capital investment to development and pilot facilities. Glagoleva uses the same figures: see G. M. Glagoleva, "Material'no-tekhnicheskoe osnashchenie nauki," *Ekonomika i Organizatsiia Promyshlennogo Proizvodstva,* No. 3, 1973, pp. 24-27. A desirable level, he says, would be 1 or 2 percent. Note that industrial development facilities *employ* over 4 percent of the Soviet industrial work force. (Glagoleva, op. cit. (1973).)

[19]OECD, op. cit., pp. 388, 390. Unfortunately, we have not yet found any comparative figures for institute-based facilities.

[20]Berliner, op. cit.

[21]Bashin, op. cit., provides one of many Soviet observations on this score.

[22]Kushlin, op. cit., p. 87.

direction is that in enterprise-based pilot facilities, only 18.5 percent of the employees are engaged in "research or experimental engineering work."[23] Many of the rest are presumably employed in routine production.

For their part, the personnel of pilot-production and test facilities have an incentive to go along with the *glavk,* because the bonus system rewards them for accepting orders for current output. So long as this is so, the problem of takeover will continue. At the moment, there are no special regulations governing planning, reporting, and bonuses for development and pilot-production units.[24] They must contend with a solidly anchored conviction throughout the bureaucracy that RD&D should pay its way *now,* and that conviction, if anything, appears to be spreading. But there are some experiments under way to attempt to deal with the problem. The Ministry of Power Equipment (*energeticheskoi mashinostroeniia*) rewards its experimental facilities according to the percentage of experimental projects currently in its shops, and bonuses are connected to completion of innovative projects, not for series production.[25] How effective these measures have proved to be we do not know.

We should not conclude, incidentally, that if an experimental facility is described in the Soviet press as having been taken over by series production tasks, it is not contributing to technological innovation just the same. Rather, having successfully developed a new product or process, the pilot facility may *then* become the victim of its success, if its innovation meets an urgent need. Thus, for example, one experimental plant has recently developed a fast, inexpensive method of heat-treating drilling pipe, which is badly needed for stepped-up petroleum exploration in Siberia. For the past year the plant has been handling series production of the new piping, supplying three ministries involved in petroleum and gas extraction.[26] This case illustrates the problem: Suitably equipped experimental facilities have the capacity to bring a new product on line quickly, but in view of the usual obstacles to diffusion of a new technology to older enterprises, they may end up mass-producing it themselves, in effect losing their experimental status and their significance as a force for further innovation.

Despite the imprecise definition of what development and pilot-plant facilities consist of, Soviet sources agree that they do make a big difference in technological innovation. More than half of the scientific projects that have been subjected to a careful test or development phase, they say, subsequently find their way into industrial production without major alteration; but that figure drops to 15 or 20 percent for projects that have not.[27] Organizations with adequate pilot-production facilities have lower lead-times and costs than organizations without them (by as much as half for both), and the quality of their product is greater.[28]

Some industries appear to be considerably better equipped with test facilities than others, and there is at least a rough correlation between the extent of availability of test facilities and the length of lead-times in each industry (see Table 2).

It is interesting that an industry such as electrical engineering, having not much greater density of test facilities than the tractor and agricultural-machinery industry, nevertheless claims much shorter lead-times for prototype development. The answer may be that the electrical engineering industry actually consists of two parts, one producing large machinery for power generation and transmission, and the other, consisting of more numerous but smaller

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[23]Glagoleva, op. cit. (1977b), p. 106.

[24]Tikhomirov, op. cit. (1978b), p. 10. Test facilities and pilot-production plants have a somewhat ambiguous legal status. Pilot production facilities are officially classified as "auxiliary" (*vspomogtel'nye*). Glagoleva, op. cit. (1977b), p. 110; K. I. Taksir, *Nauchno-Proizvodstvennye Ob"edineniia,* "Nauka," Moscow, 1977, p. 9.

[25]Bashin, op. cit.

[26]V. Vasilets, "Velikolepnaia semerka," *Pravda,* December 10, 1979.

[27]Ibid.

[28]Kushlin, op. cit., p. 82.

Table 2

COMPARISON OF LEAD-TIMES WITH AVAILABILITY OF TEST FACILITIES, SELECTED INDUSTRIES, 1975

Branch of Industry	Lead-Time to Completion of First Prototype[a] (years)	Enterprises with Test or Pilot-Production Facility (%)
Machine tools	2.7	44.2
Tractors and agricultural machinery	3.6	36.4
Heavy, power, and transportation machinery	3.2	56.1
Automobile industry	2.8	62.1
Construction and road-building machinery	2.6	55.2
Instrumentation industry	1.9	82.8
Electrical engineering	2.5	38.9
Machinery for consumer and food industries	2.9	47.7
Chemical and petroleum machinery	2.8	46.5

SOURCE: Glagoleva, op. cit. (1977b), pp. 58 and 65.

[a]From the beginning of design.

firms, which produces electricity-using equipment, including many small electrical consumer appliances. The most significant innovation and the shortest lead-times are concentrated in the former half of the industry, and the most elaborate test facilities are to be found there as well.

For example, Elektrosila, the country's leading manufacturer of large turbogenerators, maintains a $20 million test facility which, among other things, enables its engineers to test 1000 and 1200 megawatt generators under full load. The DC Institute in Leningrad, the country's lead institute for high-voltage transmission, has a new test facility of approximately the same cost, which includes a five million volt impulse generator and a computerized control system (the latter built by TUR of Dresden). Subversion of test facilities by routine production tasks does not appear to be a problem in these advanced firms. For example, the Dzerzhinskii Heat Engineering Institute in Moscow maintains a thermal generating plant as part of its test facilities. Though the plant is connected to the Moscow power system and is even assigned an output plan, the institute is apparently not under any particular pressure to meet it, and devotes the generating plant to its own research needs.[29]

These are unusually elaborate and expensive facilities—more elaborate in some ways, in fact, than those of their American counterparts in the same field, firms such as General Electric and Westinghouse. The American firms do not test large generators under full load in their own plants, or maintain large facilities for physical simulation of large networks. They can dispense with the expense of such large test facilities because they achieve the same results in other ways, through computer modeling and component testing, for example, and through testing on-line. Soviet engineers say that it is not easy for them to do on-line testing, in view

[29]The above examples are drawn from site visits made by the author in October 1979, under the auspices of the National Science Foundation.

of the tight output targets and low reserve capacities of Soviet utilities. However, it is also possible that the need for elaborate testing by the producers reflects the relatively inconvenient locations of many users' operating sites (e.g., power-stations in remote Siberia).[30] Another possibility is that the large generator producers have only one customer, the Minister of Power, who, as the sole buyer, has some power to impose high standards.

These points, in turn, suggest the importance of national differences in the environment in which innovation takes place. There is the intriguing possibility that innovation under Soviet conditions *requires* more elaborate test facilities than in American industry. However, it is difficult for the outside observer to tell to what extent the Soviet self-criticism is justified, for their writings contain little detailed description of what existing test facilities consist of, the quality of their equipment and staffs, the space devoted to them, and their relations with clients and superiors. It is also impossible to tell what the writers' standards of sufficiency might be. All the same, the troubles of test- and pilot-production facilities appear to constitute a major explanation for Soviet problems with innovation. A vital transmission mechanism between research and production is being neglected and subverted as a result of the biases of the ministry bureaucracies. It is not surprising, then, that one occasionally hears calls for the creation of something like an Academy for the Industrial Sciences, administratively independent from the ministries, and equipped with its own test facilities.[31] As we shall see in the last section of this report, some parts of the Academy of Sciences have undergone important changes along these lines in the last decade.

What are the consequences of the weaknesses of Soviet test and pilot-production facilities for our understanding of the roles of foreign technology in Soviet innovation? Such facilities are *adapters* of ideas that have already reached the stage of embodiment into new products and processes, and as such they are essential agents in preparing the way for the mass diffusion of new production capability throughout their industry. If Soviet problems with this vital link in the innovative cycle are as great as the Soviet literature appears to indicate, then the net effect is to lessen the ability of Soviet industry to take advantage of foreign ideas and developments that have not already been fully tested and embodied into a developed product or process that is ready for mass production. A foreign patent, by this reasoning, will be more difficult to use than a fully built foreign plant. To the extent that technology transfer consists of higher-order quantities such as skills, know-how, and managerial techniques, rather than objects, the Soviets require a strong network of test facilities to derive benefits from them. Consequently, one of the most important tasks for future American investigation is to develop, for selected industries, a better understanding of the strengths and weaknesses of Soviet test and pilot-production facilities.

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[30]These items of information come from discussions held in the author's presence between American executives with knowledge of General Electric and Westinghouse, and Soviet counterparts from the Dzerzhinsky Thermal Engineering Institute, Moscow, October 1979.

[31]See, for example, the series of articles published in *Literaturnaia Gazeta* under the general heading, "Akademiia dlia neakademicheskikh nauk," March 14, April 21, July 28, August 18, and October 6, 1976.

V. PUTTING R&D UNDER ONE ROOF WITH THE SCIENTIST IN CHARGE: THE NPO EXPERIMENT

In the late 1960s, in the wake of the 1968 decree that launched most of the experiments in innovation policy described in this report, yet another experiment appeared in Soviet R&D management, the scientific-production association (*nauchno-proizvodstvennoe ob'edinenie,* or NPO). Patterned to some extent after Soviet observations of American high-technology corporations, NPOs are designed to overcome the gap between science and industry by putting the entire research and development cycle within a single organization, under a single management, a single plan, and a single system of supply and reward. Their most distinctive feature, however, is that in an NPO the scientists are supposed to be in charge.

Thus the NPOs implicitly embody one of the older but still common themes of Soviet R&D philosophy: that science is the source of the most worthwhile innovations, and since industry is the source of most of the obstacles, the solution is to give the scientist direct control of production facilities, to enable him to bring his ideas to fruition. The full R&D cycle, from discovery to mass production, should be under one roof, so as to finesse the bureaucrats' endless authorizations and approvals, required whenever a project crosses the line from one organization to the next. Now about 150 strong, the NPOs are one of the most interesting attempts to bridge the gap between research and product through organization design.

Yet their success depends on two conditions: *first,* on whether the advertised "single roof" actually comes into existence, and whether it is made sufficiently strong to serve the purpose for which it is intended; *second*, on whether NPOs can overcome the disincentives that make the typical Soviet enterprise reluctant to innovate. The generally critical tone of the Soviet literature suggests that the NPOs have not been particularly successful yet. However, we shall see that many Soviets recognize these problems, have further mulled over both Soviet and Western management experience, and are now experimenting with improvements in the NPOs' basic design.[1]

WHY MOST NPOs DO NOT CONSTITUTE SINGLE UNITS

Visiting Leningrad NPOs in search of a model, a group of Siberian executives were distressed by what they found:

> The management functions were not centralized. Separate accounting and separate planning divisions, absolutely separate incentive systems between the research and production divisions. We were unpleasantly surprised to see in a number

[1]Two recent Western analyses of NPOs, though they identify the same problems as this report, find the NPOs more significant and successful than this writer does. See Paul Cocks, "Organizing for Innovation in the 1970s," Occasional Paper No. 54 of the Kennan Institute for Advanced Russian Studies, The Wilson Center, Washington, D.C., November 1978; and Julian Cooper, "Innovation for Innovation in Soviet Industry," a chapter scheduled for publication in the second volume of the collection edited by R. Amann, J. M. Cooper, and R. W. Davis, *The Technological Level of Soviet Industry,* Yale University Press, New Haven (forthcoming). For two recent Soviet views, see O. G. Gvakhariia, "Kakim byt' NPO?," *Ekonomicheskaia Gazeta,* No. 7, February 1980, p. 6; and B. I. Tabachnikas, "Ot edinstva organizatsionnogo—k ekonomicheskomu," *Ekonomika i Organizatsiia Promyshlennogo Proizvodstva,* No. 8, 1979, pp. 19-27.

of Leningrad NPOs, for example, on the same floor and right next door to one another, one bookkeeping department for the NPO, one for the special design bureau, and one for the production plant. Where then are the advantages of an NPO?[2]

The picture is apparently not much different in most NPOs. Their constituent units—in most cases a research institute, a design bureau, and a plant—are divided, to begin with, by different organizational histories and professional backgrounds, often by sheer physical distance also. But what prevents these obstacles from being overcome is divisive forces bearing on each of the units from outside, imposed by the higher authorities, usually separate ones, to which they continue to report.

Most NPOs are loaded down with the same taut output plans and heavy production targets that they had before they were created, mostly for products unrelated to the research profile of the research institute supposedly in charge. The result is the opposite of what was intended: The institute is technically in charge but in practice unable to take effective control. The dominance of routine production over research and development in the NPOs' activities has been extensively documented by Soviet sources. In *Elektrokeramika*, *Akkumuliator*, *Volna*, and *Plastik* the production plant is the unit actually in charge;[3] in *Elektroapparat* and *Kondensator* very little research goes on,[4] and similar comments can be found about many other NPOs as well.

The higher priority of production over research in most NPOs shows up in inequalities in salaries and bonuses: Their factory employees usually make higher monthly salaries than the scientists in their research institutes, and the bonuses of the former are an order of magnitude higher.[5] Consequently, it appears that the internal divisions within the NPOs, reinforced by external forces, can only be resolved if these are counteracted by stronger ones, such as meaningful high-level intervention and supervision. However, despite the small number of NPOs and the official publicity that has surrounded them for the last ten years, they have apparently not been given the high-level preferential treatment, the suspension of the ordinary rules, and the privileged access to supplies and equipment that they require and that one might have expected.

First, implementation has been left largely to the initiative of the ministries themselves. According to one science-policy expert, most NPOs in the early days were put together at the local level, either by "local agencies or by the *glavki* of the various ministries."[6] Leningrad seems to be an important exception, possibly because of the strong role of the Party apparatus in encouraging NPOs. The oldest, most heavily studied, and presumably the best NPOs are located in that city. Elsewhere, the state of NPOs is uneven from field to field. Some ministries plunged forward prematurely, others have held back and seem to resist creating NPOs. For example, the head of the State Committee on Science and Technology's section for research organization and economics describes how the Ministry of Agriculture threw together the *Sistema* NPO without adequate preparation or study, anchoring it to a weak research laboratory extracted from a larger agricultural institute in Moscow. The Ministry of Chemical and Petroleum Machine-Construction (then a single organization, now split in two) plunged

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[2]Tsaregorodtsev and Kvint, op. cit.

[3]Taksir, op. cit.

[4]Ibid., p. 39.

[5]Bonuses to employees in the research institutes average 4 and 5 percent (another source mentions a maximum of 10 percent of their monthly salaries), whereas those of the factories officially subordinated to them amount to 30 or 40 percent. Kushlin, op. cit., p. 70. This particular figure is from 1971, but there is no suggestion that the situation has changed much since.

[6]G. Dzhavadov, "The Potential of Associations," *Pravda*, September 18, 1974, p. 2. Translated in *Current Digest of the Soviet Press*, Vol. XXVI, No. 38, p. 6.

ahead and between 1970 and 1971 created 10 NPOs, most of them amounting simply to a research institute with a small industrial facility. In contrast, as of the beginning of 1976, light industry and the food industry, particularly dairy products, have lagged behind.[7]

In the beginning, no single statute spelled out the status of NPOs, and even now the Central Statistical Administration does not recognize NPOs as a distinct entity.[8] In 1975 this was partly remedied in a model statute (*tipovoe polozhenie*) from the USSR Council of Ministers. Among other things, the 1975 statute specified that an NPO constituted a single legal entity, its constituent units being fully absorbed by it and losing all independent identity.[9] However, a *tipovoe polozhenie* is only a broad guideline. Most NPOs still do not control their own member organizations, or operate under a single plan, or have a single budget and bonus system. One can only conclude that the guideline has not been energetically enforced.

A further clue to their real priority is that most of the NPOs are buried far down in the organization chart: Two-thirds of them as of 1977, including such major Leningrad NPOs as *Plastpolimer* and *Gidrolizprom*, were subordinated to middle-level echelons of management, such as *glavki* or their newly named equivalents (*vsesoiuznye proizvodstvennye ob"edineniia*),[10] rather than directly to ministry headquarters. A lucky few, such as *Soiuzavtomatstrom*, report directly to the deputy minister level, but they are exceptions.[11] In view of the difficulty of launching new organization types in the Soviet administrative structure, the fact that the NPOs have not benefited from high-level supervision and nurture limits their chances for effectiveness.

This apparent lack of consistent high-level attention is especially surprising when one considers that the NPOs mentioned in Soviet sources tend to be found (although not always) in advanced civilian technologies of the kind we discussed in the first section of this report. Three groups stand out clearly:

- *New materials*
  - metals
  - glass
  - wood products
  - polymer fibers and plastics
  - new steels
- *Advanced types of machinery*
  - agricultural machinery
  - automated distribution of natural gas
  - automated process control
  - automated mining machinery
  - petrochemical machinery
  - paper and wood pulp
- *Other advanced sectors*
  - cryogenic engineering
  - transport container systems
  - electronics and electrical engineering
  - digital instruments

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[7]Taksir, op. cit., pp. 158-159.
[8]Kushlin, op. cit., p. 12.
[9]Ibid.
[10]V. Pokrovskii, *Povyshenie effektivnosti nauchnykh issledovanii i razrabotok*, "Ekonomika," Moscow, 1978, p. 156.
[11]Tabachnikas, op. cit., p. 23.

The importance of these fields makes it all the more surprising that NPOs have not been given the top-level attention that they need.

However, this question is difficult to judge in the aggregate, since there is a great variety among NPOs. We now consider the experience of one of the best known of them, the NPO in charge of advanced polymer development, *Plastpolimer.*

PLASTPOLIMER

Earlier in this report we saw that the chemical industry has been heavily dependent on imported Western plant and technology for the past twenty years. This reliance on the West is especially great in the sector of modern synthetic materials, such as plastics and fibers. What efforts have the Soviets made to develop their own independent capacities? We focus in the next few pages on the NPO in charge of thermoplastics research development in the Soviet chemical industry. Working in what is perhaps the *least* independent sector in all of advanced Soviet industry, what does this NPO do and what are its problems?

Formed in 1969, the Leningrad-based chemical association called *Plastpolimer* is perhaps the most intensively studied of all NPOs, and it is often cited in the Soviet literature as a model for others to follow. *Plastpolimer* occupies a critical position in the Soviet chemical industry, as the lead institute for industrial development of polyolefins, polystyrols, and fluoroplastics.[12] *Plastpolimer* is responsible, as one source puts it, for the "productivity" of chemical equipment at plants with a combined output of nearly 2 million tons per year,[13] no small task in a plastics industry whose total output is around 5.5 million tons per year. A sizable percentage of that, perhaps as much as half, comes from plants purchased in the West.[14]

The units that are joined together in *Plastpolimer* have a long history. Its main research institute, NIIPP (the Scientific Research Institute for Polymer Plastics), was the first Soviet research institute for plastics, founded in 1932. Its production plant, the Okhtinsk factory, is one of the oldest in Russia, built in 1719 on the orders of Peter the Great. Until the late 1920s it made gunpowder, then became the first Soviet research center for first-generation plastics, especially bakelite and celluloid.[15] NIIPP and Okhtinsk have had some informal association in the past: After World War II, they cooperated in developing Soviet production of polyvinylchloride.[16] From 1956 to 1962, working under a special order from the Ministry of the Chemical Industry, NIIPP and Okhtinsk teamed up to set up industrial production of polyethylene at low pressures. They completed the job in six years, an achievement that one Soviet source calls remarkable, since lead-times in the chemical industry were then running between 12 and 15 years.[17] Soiuzkhimplast, the industrial association (*vsesoiuznoe proizvodstvenoe ob"edinenie*) to which *Plastpolimer* is subordinated, is also a product of the 1930s.[18] These past links remind us that the basic principle of NPOs is not a new one, but has been around in Soviet technology policy for fifty years.

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[12]Taksir, op. cit., p. 50.

[13]B. Sazhin, "Uchenyi v rabochem kollektive," *Pravda,* December 24, 1977.

[14]Central Intelligence Agency, op. cit. (1978), pp. 7-8.

[15]Ronald Amann, "The Chemical Industry," in Amann, Cooper, and Davies, op. cit. (1977), p. 273.

[16]Ibid.

[17]P. N. Zavlin, A. I. Shcherbakov, and M. A. Iudelevich, *Trud v sfere nauki,* 2nd ed., "Ekonomika," Moscow, 1973, pp. 119-120. Low-pressure polyethylene is an example of the puzzling pattern that Amann talks about in his discussion of innovation in the Soviet plastics industry: Despite the success claimed for NIIPP and Okhtinsk, the Soviet Union subsequently contracted with Salzgitter of West Germany for two large low-pressure polyethylene plants, in 1962 and 1972. See Amann, op. cit., pp. 276 and 280.

[18]Ibid., p. 273.

But these early links have not spared *Plastpolimer* the problems of integration that have plagued other NPOs. The main problem is different profiles: NIIPP evolved in the 1950s into research on thermoplastics, while Okhtinsk did not change. Its output mix consisted as before of celluloid, epoxy resins, vinylacetate, adhesive tape, and a wide variety of similar products—in short, large-scale production, outdated technology, and no innovation.[19] By 1969, when *Plastpolimer* was officially formed, NIIPP and Okhtinsk had become two very different organizations: Only 20 percent of the Okhtinsk plant matched the research profile of NIIPP and the mission of the new organization.[20]

The location of the constituents of the new NPO has been a problem too. On the one hand, *Plastpolimer* has been fortunate in having its main units in the same city (this is not usually the case). As time went on, *Plastpolimer* picked up additional units in other cities (Erevan, Grozny, Novosibirsk, and Novopolotsk), but the center of gravity is still Leningrad.[21] On the other hand, the Okhtinsk plant could not be expanded much, for it was cramped in the middle of a residential area of Leningrad. Therefore, any new products and processes produced at Okhtinsk would have to displace older ones, with temporary losses of output and touchy problems of retraining and retooling. Consequently, *Plastpolimer* faced a serious management problem, for unless the composition of output from the Okhtinsk plant could be changed, the new NPO would be deprived, in effect, of most of its pilot-production capability. In addition, *Plastpolimer* had to contend with the same problems in achieving unification as other NPOs.

Thus the story of *Plastpolimer* is to a great extent its search for effective management. The first three years were a difficult period, as the constituent parts of the NPO contended for domination. To unify the NPO, the Party *obkom* (the local district office of the Party apparatus) tapped a strong personality as chairman of *Plastpolimer's* Party committee, Popov, the former director of the design bureau that had been amalgamated into *Plastpolimer* the year before.[22] As general director, the ministry picked a chemical engineer with both research and production experience, Z. N. Poliakov (formerly head of the Polotsk chemical complex).[23] Faced with the long-obsolete Okhtinsk plant, the new management team converted some of its shops into pilot-production divisions, but in doing so they had to work hard to overcome the reluctance of the shop chiefs, who continued to focus on meeting current output plans, as indeed their incentive structure encouraged them to do. In this they had the support of *Plastpolimer's* hierarchical superior, Soiuzkhimplast, which imposed production targets on the Okhtinsk plant for such items as plastic toys, unrelated to the innovative policy the NPO's management was trying to pursue. When the NPO's Party committee chairman began lobbying Soiuzkhimplast for greater cooperation, it responded by bringing pressure against him through the local Party hierarchy (*raikom*).

Popov, meanwhile, began making innovative use of the NPO's Party structure as a means of promoting unification. Finding that separate Party committees still existed for each of the former constituent units, Popov began calling special joint Party meetings that cut across organizational lines, summoning Party members from the whole NPO by common specialty—one meeting for people in polyolefins, another for fluoroplastics, etc. This unorthodox approach worried the local *raikom*, but Leningrad's top Party organ, the *obkom*, apparently defended the NPO. Popov claimed some success in softening the divisions of *Plastpolimer's* constituent units by his unconventional procedures.

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[19]B. Chertkov, "Partkom firmy," *Leningradskaia Pravda*, March 2, 1972.
[20]"NPO—provodnik tekhnicheskogo progressa," *Ekonomicheskaia Gazeta*, No. 32, August 1979, p. 8.
[21]In addition, Plastpolimer has divisions in Omsk and Shevchenko.
[22]Chertkov, op. cit.
[23]"NPO—provodnik. . . ," op. cit.

Nevertheless, the problem of converting the Okhtinsk plant was not resolved, for as of 1972, when the NPO's research institute needed to have a new product test-produced, it usually had to make arrangements with other chemical plants around the country, even though Okhtinsk was supposedly the NPO's own in-house test facility. Efforts to bring the Okhtinsk plant's output closer to the NPO's profile were only partially successful; for example, some of the research staff tried to object to the use of Okhtinsk for the production of toys, but without success. The inertia imposed by the plant's current output plans was too great to overcome. Nevertheless, even though complete conversion of the Okhtinsk plant apparently did not prove possible, the NPO's management by 1973 was able to terminate some 20 million rubles a year worth of production of obsolete items such as celluloid, adhesive tapes, and polyvinyl separators.[24] By 1973 *Plastpolimer* had managed to triple the volume of its demonstration and pilot-production work, even though the floor space devoted to it had increased by only half.[25] As a partial measure of level of effort, the funding figures are especially striking: The funds devoted by *Plastpolimer* to the development of pilot-production capacity ties grew from 1 million to 2.3 million rubles annually over five years (1969-1973).[26]

One indication of the extent to which the NPO's management was able to bring the constituent units into line is the proportion of unrelated work each one continued to perform—unrelated, that is, to the research profile of the research institute supposedly in charge. When the NPO was first assembled, that percentage was very high: 35 percent in the case of the design organization, 72 percent in the "start-up and debugging" (*puskovo-naladochnyi uchastok*) unit, and 80 percent in the Okhtinsk production plant. Five years later, the figures had fallen to 20 and 40 percent, respectively, for the first two units, indicating that they had been brought considerably (though still not completely) in line with the NPO's research unit.[27] But even as late as 1979, after ten years of effort by *Plastpolimer's* managers, only 43 percent of the Okhtinsk plant's output consisted of the thermoplastics that the NPO's mission called for.[28] And *Plastpolimer*, we should remember, is considered one of the leading NPOs.

Where do things stand currently? In an interview with *Ekonomicheskaia Gazeta* in 1979, General Director Poliakov sounded discouraged. Echoing the complaints found elsewhere in the Soviet press, he declared that much of the performance of NPOs is evaluated on the basis of their success in meeting monthly and quarterly output plans, just like any other industrial enterprise. This turns the NPO director into an ordinary enterprise director, because he has to devote most of his attention to meeting targets and getting supplies; and it turns research scientists into production supervisors. However, *Plastpolimer* is a little better off in this respect than most other NPOs, Poliakov added, because of steady support from the province and city Party committees, but he declared the situation unsatisfactory just the same. (There was no mention of Popov's experiments in Party management.) Most of the problem, as before, comes from the Okhtinsk plant. Despite renovation and expansion, the plant remains quite inadequate as the principal test-production facility for the Soviet thermoplastics industry. *Plastpolimer* is lobbying to have a new pilot-production facility built in Leningrad or to have an existing plant transferred to it (minus its current-output targets), but so far without success.[29]

In view of these problems, what has *Plastpolimer* managed to achieve? The aggregated statistics tell little: For example, from *Plastpolimer's* director we learn that since *Plastpolimer*

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[24] Taksir, op. cit., p. 60.
[25] Ibid., p. 51.
[26] Ibid., p. 52.
[27] Ibid., p. 59.
[28] "NPO—provodnik . . .," op. cit.
[29] Ibid.

was created Soviet output of thermoplastics has tripled.[30] Perhaps more revealing are the individual success stories for which *Plastpolimer* is occasionally awarded a prize or is singled out in the press. A 1977 news item reports that *Plastpolimer* designed a pilot production plant for ethylene-vinylacetate copolymerization in a total time of nine months.[31] A successful design for producing polystyrol by the incomplete conversion process took a year and a half, whereas (according to one source) a similar project before the creation of the NPO would have taken between two and four years.[32] In 1976 the NPO, together with a team from East Germany, was awarded a State Prize for the successful development of "Polymer-50."[33] Polymer-50 is now in production in a specially built plant at Novopolotsk in Byelorussia. There have been some successes in developing production of fluoroplastics,[34] for which the military is a prominent customer.

We might expect one of *Plastpolimer's* main jobs to be to participate in the transfer and adaptation of foreign technology, working with Western companies and Soviet contractors in starting up Western-built plants. What effect does this seem to have had on *Plastpolimer's* own ability to generate advanced technology? On the one hand, the fact that *Plastpolimer* can point to no great successes in moving beyond Western technology or even duplicating it without assistance may mean that *Plastpolimer* has not developed strong independent capacities, perhaps even as a result of deliberate policy in the ministry. Another possibility is that *Plastpolimer's* abilities or lack of them have nothing to do with the apparent Soviet failure to develop new chemical technology of their own but that the explanation lies rather in the relative economic attractiveness of Western technology during the 1960s and 1970s, and the weaknesses of the Soviet chemical equipment and construction industries.[35] At this point, it is not possible to tell.

NPOs like *Plastpolimer* have potentially important implications for the Soviet ability to learn from technology transfer, move beyond it, and generate their own. Because NPOs include under one roof a wide range of scientific, design, and managerial talent, and because they are (at least in principle) dedicated to the task of innovation, they should be especially well suited to assimilating, and then building upon, "higher-order" transfers, that is, ideas and know-how rather than finished products and processes. Moreover, since the NPOs are few in number and clustered in important new areas of civilian technology, it should be possible to give them a somewhat exceptional status within their industries, creating, in effect, small islands of privileged reform within an essentially unchanged overall structure.

However, in order to succeed they must form truly integrated units and be able to influence the later stages of the innovation cycle. The evidence we have seen so far suggests that the NPOs have not had the necessary high-level support to achieve this, and consequently are still far from fulfilling their potential. It would not take much, it seems, to put the NPOs on a more solid and powerful footing, and so one of the most intriguing questions of Soviet technology

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[30]Ibid.

[31]B. Sazhin (First Deputy General Director of the NPO), "Uchenyi v rabochem kollektive," *Pravda*, December 24, 1977.

[32]B. I. Kozlov, ed., *Organizatsiia i razvitie otraslevykh nauchno-issledovatel'skikh institutov Leningrada, 1917-1977*, "Nauka," Leningrad, 1979, pp. 141-142.

[33]Kozlov, op. cit., p. 141.

[34]"NPO—provodnik . . .," op. cit.

[35]Philip Hanson's survey of British firms who have supplied chemical equipment to the Soviet Union mentions Soviet weaknesses in contractor skills, such as coordination of supplies and detailed engineering, as well as problems of precision and reliability in the manufacture of certain large equipment, such as high-pressure tanks and tubes, valves, and compressors. Philip Hanson and Malcolm R. Hill, "Soviet Assimilation of Western Technology: A Survey of UK Exporters' Experience," in U.S. Congress, Joint Economic Committee, *Soviet Economy in a Time of Change*, Vol. 2, U.S. Government Printing Office, Washington, D.C., October 1977, pp. 582-604.

policy is why the Soviet leaders have not seen fit (or conceivably have been unable) to take the necessary steps. In Leningrad, where the head of the Party organization, Politburo member G. V. Romanov, has taken a consistent personal interest in technology policy, NPOs have been more successful than anywhere else. Perhaps the NPOs are not viewed elsewhere as the most promising line of reform since they do not deal with the reluctance of ministerial "chief administrations" to innovate, but instead only add one more layer to an already complex bureaucratic structure. Table 3 presents a partial list of NPOs, reflecting all organizations located up to February 1981.

Table 3

PARTIAL LIST OF NPOs
(Reflects all organizations located up to 2/81)

Name	Specialty	Headquarters
Agropribor	agriculture	
Akkumuliator	electrical equipment	
Avtomatgormash	automated machinery for coal-mining	
Biokhimreaktiv	biochemicals	
Bummash	paper making equipment	Leningrad
Burevestnik		
Elektroapparat	electrical equipment	Leningrad
Elektrokeramika	electro ceramics	Leningrad
Elva	computerized control systems	Tbilissi
Gidrolizprom	biochemicals	Leningrad
Istochnik	batteries	Leningrad
Kazsel'khoz-mekhanizatsiia	agricultural machinery	Alma-Ata
Kompleks		Volgograd
Kondensator	electrical equipment	
Krasnaia zaria		Leningrad
Krasnogvardeets		Leningrad
Kriogenmash	cryogenic engineering	
Lenelektronmash	(computer systems)	Leningrad
Lenteplopribor		Leningrad
Mikrobioprom	(wood pulp hydrolysis)	Leningrad
Nauchplitprom		
Neftekhim	petrochemicals	
"Goskomizobreteniia"	new inventions	
NPO im. Polzunova	power-generating equipment	Leningrad
Restavrator	restoration of historic monuments and buildings	
NPO "VNIIM" im. Mendeleeva	micro ball-bearings, standards	Leningrad (Gosstandart)
Olainfarm	pharmaceuticals	near Riga
Pischepromavtomatika	food processing	
Plastik	plastics	(units in Zagorsk-Khar'kov)
Plastmassy	plastics	
Plastpolimer	polymers and chemical engineering processes	
Positron	(inter alli: automated process control)	
Proletarskii zavod	(machinery and equipment for ships)	

Table 3—continued

Name	Specialty	Headquarters
Ritm	shipbuilding	Leningrad
Roselektronmash	(computer systems)	Novosibirsk
Sakhar	sugar	Kiev
Sibtsvetmetavto-matika		(Krasnoiarsk)
Sistema	tractor and farm machinery	Moscow
Soiuzavtomatstrom	computerized management systems for process control	Leningrad
Soiuzgazavtomatika	automated distribution of natural gas	
Soiuzmorgeo	marine exploration for oil and gas	
Soiuznauchplitprom	wood processing, new materials furniture	Moscow
Soiuzpromgaz		
Soiuzsteklomash	glass	Moscow
Soiuztransprogress	transport container systems	
Soiuzturbogaz (1976)	gas industry	Khar'kov (plant in Uzhgorod Shchebelink)
Spetstekhosnastka		Odessa
Termopribor	heat-measuring instrumentation	Lvov
Tsiklon	(wind power sources)	
Tulachermet	ferrovanadium, vanadium pentoxide, continuous casting processes, powder metallurgy, and oxygen-hearth smelting	Tula
Turan	hydrogeology	Tashkent and other Central Asian cities
VNIImetmash	(among others: continuous steel casting)	
Volna		
Znamia truda	petrochemical machine-building	Leningrad
Zvezda		Leningrad
( )	electronic instruments	Voronezh

VI. THE INCREASING INVOLVEMENT OF THE ACADEMY OF SCIENCES IN TECHNOLOGICAL INNOVATION

The USSR Academy of Sciences and its counterparts at the republic level (notably the Ukraine) have played a prominent part in applied research and development, including military, since the 1930s. However, the extent of their involvement has varied, reaching a relative high during the late Stalin period and a relative low in the mid-1960s.[1] In recent years, the trend has been once again toward more emphasis on practical applications of its scientific work. This section discusses two important aspects of this trend.

How one views the Academy's growing involvement in technological innovation depends, once again, on one's diagnosis of Soviet problems. The Soviet literature's criticism of the ministries and enterprises, combined with the emphasis of recent Western literature on the importance of demand factors in innovation, might lead us to expect that the recent changes in the Academy of Sciences are not really relevant to the Soviets' most serious problems, and reflects the lingering survival of old-fashioned views of what innovation is all about. But the Western literature also emphasizes that advances in basic research have been the key to some of the most fundamental, if not the most numerous, innovations in the last generation and that, if anything, the role of basic research in innovation is growing, compared to what it was a century or a half-century ago. In the Soviet case, one must add one very important fact: Few organizations can match the prestige and the clout of the Academy of Sciences and, therefore, its involvement in the later stages of the innovation cycle guarantees a certain respectful attention on the part of ministerial producers. In fact, the Academy has played a consistently prominent role at the high-priority end of Soviet industrial innovation, especially in space and military-related technologies, so much so that the Academy's growing involvement as described here might more properly be viewed as an effort to extend the traditional zone of high priority to what have been until now lower-priority areas, so that the managerial devices we will discuss in this section may well turn out to have antecedents in the Academy's military and space-related work.

THE SIBERIAN DIVISION

Involvement in Applied Research and Technological Innovation

The Siberian Division (SOAN) occupies an unusual position in the Soviet Academy of Sciences. Ever since its creation in 1957, it has played a role of an innovator.[2] It promotes high mobility and interdisciplinary contact among its institutes.[3] It operates Novosibirsk University

[1]Bruce Parrott, *Technological Innovation in the USSR,* M.I.T. Press, Cambridge, Massachusetts (forthcoming).

[2]For a brief history of the founding and early years of the Siberian Division, see the case study prepared for the Joint U.S.-Soviet Working Group on Science Policy, scheduled for publication in National Academy of Sciences, National Research Council, *Systems for Stimulating the Development of Fundamental Research,* Washington, D.C., 1978, pp. VIII-1 to VIII-70.

[3]See, for example, a forthcoming study by Simon Kassel of The Rand Corporation, "Soviet Laser-Fusion Research Organizations."

as a virtual appendage of itself (in a country where the university system is relatively divorced from research).[4] It has supported scientific disciplines that have been neglected or repressed in Moscow.[5] Its computer center is one of the best in the Academy system, and it maintains its own production facility to make the latest in scientific instrumentation.[6] And in keeping with this generally pioneering spirit, the Siberian Division has been actively involved in developing new mechanisms for the management of applied research and technological innovation.

Since its beginnings, the Siberian Division has devoted a large part of its work to applied research. Lately, that share has been growing, and so has the attention devoted to development and demonstration. A rough indicator of this is the proportion of the SOAN's budget financed through direct contacts with industrial customers (*khozdogovora*), which has risen from 6 percent in 1965 to 20 percent in 1975,[7] and in some institutes to as much as 50 percent.[8] In recent years institute directors have been encouraged to seek out as much contract business as they can. Thus, the director of the Irkutsk Institute of Organic Chemistry takes clear pride in reporting that recently his institute overfulfilled its contract plan by 2.5 times.[9]

But economic contracts alone do not measure the full extent of the Siberian Division's involvement in applied research and development. The SOAN leadership, under prodding from the government and the Academy Presidium in Moscow, has been trying to improve patenting services and to persuade basic researchers to take the trouble to patent the potential applications of their work. And while up to 1966 patent departments had only amateur status and little prestige,[10] since then a corps of professional patent specialists (*patentovedy*) has appeared in most institutes, and the number of patents awarded (*avtorskie svidetel'stva*) increased by one-third in the Siberian Division from the Eighth Five-Year Plan (1965-1970) to the Ninth (1971-1975).[11]

In the mid-1970s, in sum, the Siberian Division of the Academy was more heavily involved in applied research and development than the central USSR Academy;[12] and its involvement appears to be growing rapidly. Consequently, it is forced to confront the problems of the R&D cycle in more acute form than is true for the Academy as a whole. This has stimulated a search for new management devices and schemes.

This discussion begins with a brief look at the "traditional" devices employed by the Siberian Division, such as direct ties with industrial enterprises through "economic contracts" (*khozdogovora*) and missionary work by the Siberian scientists in industrial factories. We

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[4]S. T. Beliaev, "Rol' universiteta v podgotovke kadrov dlia nauki," *Vestnik Akademii Nauk*, No. 3, 1976, pp. 13-35.
[5]See, for example, the autobiography of the geneticist N. P. Dubinin, *Vechnoe Dvizhenie*, Moscow, Politizdat, 1973.
[6]Nesterikhin, op. cit.
[7]Kushlin, op. cit., p. 138. The proportion may have continued to rise since then: During a visit by the author to a series of Soviet institutes in 1976, the figure quoted was 25 percent (U.S.-Soviet Working Group, September 1976).
[8]At the Institute of Mining Technology, the proportion is 50 percent (E. I. Shemiakin, "Vnedrenie, effektivnost', stimulirovanie," *Ekonomika i Organizatsiia Promyshlennogo Proizvodstva*, No. 3, 1977, p. 59), and also at the SOAN Computer Center (U.S.-Soviet Working Group visit, September 1976).
[9]M. G. Voronkov, "Voprosy vnedreniia: iz opyta Irkutskogo instituta organicheskoi khimii," *Vestnik Akademii Nauk*, No. 4, 1978, p. 44.
[10]See, for example, a description of changes in the Urals Center in M. D. Vlodavskaia, "Rezerv povysheniia effektivnosti akademicheskoi nauki," *Voprosy izobretatel'stva*, No. 7, 1977, pp. 39-42.
[11]G. I. Marchuk, "Uchenye Sibiri-narodnomu khoziaistvu," *Voprosy izobretatel'stva*, No. 11, 1977a, p. 37.
[12]According to the Chairman of the State Committee on Science and Technology, G. I. Marchuk, the ratio of what he calls "pure" to "applied" research is about 2/3 to 1/3 in the Siberian Division. That, in his opinion, is where it should stay. (G. I. Marchuk, "Strategiia poiska," *Krasnaia Zvezda*, February 9, 1978a.) Elsewhere, Marchuk has stated that he considers the right proportion for the Siberian Division to be 70 percent pure and 30 percent applied. (G. I. Marchuk, "20 let poiskov i eksperimentov," *Ekonomika i Organizatsiia Promyshlennogo Proizvodstva*, No. 3, 1977b, pp. 5-7.)

should bear in mind that, despite recent experiments, these traditional devices remain the dominant ones.

The Traditional Method of Promoting Technological Innovation in the Siberian Division: Some Examples

The traditional approach to promoting technological innovation in the Siberian Division has been to "sell" the ideas of Academic scientists to industry, usually by developing a privileged relationship with individual enterprises, usually close by in Novosibirsk.[13] The trouble with this kind of arrangement is that it depends largely on direct persuasion and informal relations, and results in long lead-times, many frustrations and dead ends, and little diffusion beyond the handful of enterprises immediately involved. According to a SOAN study, half of all aborted projects failed because of the endless approvals required from the numerous agencies involved at every stage.[14]

According to Academician Nesterikhin, such direct relations with enterprises work well only for relatively simple systems. He points to his institute's successful experience in developing the "Delta" light-pencil display system, accomplished through direct cooperation with an NPO in Voronezh; but he observes that for more sophisticated systems involving several different technologies information relations with single firms are not enough.[15]

Even the division's success stories make the same point. One of the most spectacular developments to come out of the Siberian Division has been the technique of explosive welding. Initially a serendipitous discovery, it was developed by a team of M. A. Lavrent'ev's students at the Institute of Hydrodynamics.[16] Today the technique is used in shaping pipes, making strong welds, and applying cladding to make bimetallic or sandwich composites, and it is a mainstay in atomic-power and hydropower plant construction. But it took nearly a decade for the scientists of the Siberian Division to find any interested industrial customers.[17] When they finally succeeded, it was through informal contacts with individuals. It seems quite clear from the Soviet account of this case that, but for the persistence of the scientists, this particular innovation would never have found any practical applications. Even now, diffusion of this technology remains slow.[18]

Likewise, traditional instruments like contracts are awkward instruments. In the Siberian Division, economic contracts (commonly referred to as *khozdogovora*) cannot be used to hire additional personnel, award major bonuses, or finance travel. Using contract money to acquire additional equipment for general use in the institute, which is probably their chief attraction to pure scientists, is described as "extraordinarily complicated." (For more on *khozdogovora,* see the Appendix to Part VI.)

These problems point to weaknesses of the Academy institutes themselves as agents of innovation. First, they have no facilities for taking a new product or process beyond the stage of applied research through design and development to the stage of commercial

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[13]Nesterikhin, op. cit. For example, the Siberian Division has done joint work with the Novosibirsk Aviation Plant and "Sibsel'mash," a plant for agricultural machinery in Novosibirsk. See Marchuk, op. cit. (1978a), p. 38. The Institute of Mining Technology has long had a special relationship with the Kuznetsk Metallurgical Combine, the Kyshtyma Plant, and others. (Shemiakin, op. cit., pp. 59-60.)

[14]N. Andreev, "Ideia ishchet propisku," *Komsomol'skaia Pravda,* February 3, 1978.

[15]Nesterikhin, op. cit., and K. M. Sobolevskii, "Nashi usiliia—rodine Oktiabria," *Avtometriia,* No. 5, 1977, pp. 3-6.

[16]V. Reut, "Vzryv—masterovoi," *Pravda,* May 10, 1978.

[17]The story is told at length in Ibragimova, op. cit., pp. 37-50.

[18]A. Deribas, "Vzryv-metallurg," *Izvestiia,* February 15, 1977, p. 2.

demonstration.[19] That would require equipping the Academy institutes with semi-industrial facilities. The only cases in which the Siberian Division has done this is to manufacture research equipment and scientific instrumentation, mainly for the Academy's own needs. Thus, Academician Nesterikhin's Institute of Automatic Systems and Electrometry now has a semi-industrial factory directly attached to it.[20] But the Academy is understandably cautious about allowing itself to become involved in large-scale production for other agencies, for it still considers its primary mission to be basic research. This caution is based partly on painful experience. Once an Academy institute is locked into the promotion of a new technology, it is difficult (and often impossible) to hand off responsibility for it and move on to the next innovation.[21] Finally, there is very little incentive to encourage the Academy specialist to accept the frustrations and distractions of bucking these obstacles.

In Sum: Mutual Misunderstanding and Recriminations

The list of complaints directed at industry by SOAN scientists is essentially the same as that of other scientists and journalists throughout the country; the experience of the Siberian Division has apparently not been much different. The main ones are: lack of demand for innovations from industrial enterprises;[22] the exploitative attitude of industry toward the Academy;[23] endless bureaucratic procedures, and even obstruction, owing to the institutional separation of one ministry from another;[24] occasional competition between industry institutes and the Academy of Sciences[25] (in the sense that ministries favor the projects developed by their own institutes over those developed by the Academy). All these complaints have two common themes: the evils of institutional separation and the indifference of the industrial ministries to technological innovation, particularly when it originates outside their own R&D apparatus. It is impossible to say which of these two is the cause of the other, because they are mutually reinforcing.

Industry has its own complaints about the SOAN scientists. They are much the same as complaints from industry throughout the country: The scientists are oblivious to the requirement for economic justification ("ask the scientists for economic justifications," says one design-bureau director, "and they show you their laboratory experiments!");[26] the scientists present industrialists with ideas in their raw state and drawings that would require a genius tool-and-die maker to execute;[27] and industry executives claim they do not see very many useful or usable ideas from the scientists. In a survey by SOAN, many industrial respondents claimed that SOAN scientists had not proposed anything new to them.[28]

Stories like these cast doubts on the diagnoses offered by scientists, and make one wonder

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[19]Thus, the Institute of Organic Chemistry in Irkutsk has no vivarium for animal tests of biologically active compounds (Voronkov, op. cit.); the Institute of Physics in Novosibirsk has developed scientific instruments like digital spectrogram recorders, traveling-field solenoids, bathyphotometers, but has no facilities for producing them in large quantities. (I. Terskov, "Khotia effekt podschitan," *Pravda*, May 14, 1978.)

[20]Nesterikhin, op. cit., p. 57.

[21]Buianov, op. cit.

[22]Andreev, op. cit., Ibragimova, op. cit., and Voronkov, op. cit.

[23]Ibragimova, op. cit.

[24]Nesterikhin, op. cit., p. 53, speaks of the "absurdity of separateness of branches." See also Ibragimova, op. cit., p. 49.

[25]Shemiakin, op. cit., p. 63.

[26]Andreev, op. cit.

[27]B. S. Galushchak, "Garantiia progressa," *Ekonomika i Organizatsiia promyshlennogo proizvodstva*, No. 3, 1975, pp. 62-64.

[28]Andreev, op. cit.

who the greater culprit really is: Is it industry, or is it the scientists? There are several possible tests. One is to determine who actually initiates a contract. Is it the scientist who beats the bushes to find industrial customers, or the ministry personnel who beat a path to the Academy institute? Academy officials, in interviews, give the impression that they have more business thrust upon them than they can handle, but the overall answer is not clear. A second test is to observe the reaction of industry when the innovation proposed by the scientists is risk-free and requires no capital. Such cases are frequently mentioned in the Soviet press;[29] and their very frequency tends to bolster the case of the scientists.

Dissatisfied with the results of traditional methods for the management of innovation and increasingly pressed by Moscow to show results, in the early 1970s the leadership of the Siberian Division started two separate experiments to promote further involvement of SOAN institutes in the RD&D cycle. The first is an invention of the first president of the Siberian Division, M. A. Lavrent'ev. Each of the major SOAN institutes has been given a facility for design and development, paid for by the ministry most closely related to the technology involved, but managed and controlled by the Academy. The second experiment, which has been tried in only three institutes so far, consists of a new system of payments, designed to give Academy scientists a stake in the practical realization of their ideas.

A New Organizational Device: The MKOs

Seeing the inability of local enterprises to turn the scientists' working models and drawings into proper blueprints and prototypes that would not require "virtuoso mechanics," Lavrent'ev proposed the creation of interagency design divisions, (*mezhotraslevye konstruktorskie otdely*) that could provide the junction between the institute and the enterprise.[30] Financed by the industrial ministries, but closely supervised by the Academy institutes, the MKOs would carry the scientific discoveries of the Academy through the states of engineering design and prototype development, up to the point at which the ministries could begin pilot production and scale-up. With his usual flair for promotion, Lavrent'ev coined the term "innovation belt" to describe this network of design offices and associated enterprises, and launched it with great fanfare in 1972.

Since then, 10 MKOs have appeared and the number is still growing.[31] (So far we have identified only seven.) They are sizable organizations: 500 people work at the KB for Scientific Instrumentation, and 500 eventually will work at the KB for Catalysis (Table 4).

After their first few years, the new KBs can claim some successes. For example, one of the first projects of the Special KB for Automatic Systems and Electrometry was a photoelectric counter, which had previously been submitted to a Novosibirsk instrument firm for mass production, but resulted in no action. After the SKB had worked on the project, it was resubmitted to the same firm and successfully mass-produced.[32] The interagency cooperation achieved by this particular institute has been successful enough to earn a commendation by a high-ranking Commission on Technological Innovation of the Presidium of the USSR Academy, which urged that the example of dual-subordination design offices, as practiced by

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[29] Coercitometers produced by the Urals Center; sheets of bimetallic composite from the Hydrodynamics Institute cryovacuum equipment, etc.

[30] See a collection of articles by Iu. I. Nesterikhin, A. A. Trofimuk, and others in issue No. 5, 1972, of *Ekonomika i Organizatsiia Promyshlennogo Proizvodstva.*

[31] "Akademiia—KB—Ostrasl'," *Ekonomika i Organizatsiia Promyshlennogo Proizvodstva,* No. 3, 1977, p. 45.

[32] Galushchak, op. cit., pp. 63-64.

Table 4

PARTIAL LIST OF NEW KBs OF THE SOAN INSTITUTES, 1972-1978

Name of KB	Associated SOAN Institute	Responsible Industrial Ministries
SibOKB	Institute of geology and geophysics	USSR Ministry of Geology
SKB for scientific instrumentation (has an "experimental" factory—pilot)[a]	Institute of Electrometry and Automatic Systems	Belongs to SOAN
SKTB for catalysis	Institute Catalysis	USSR Ministry of the Chemical Industry
Energokhimmash	Institute of Thermal Physics	USSR Ministry of Petroleum and Chemical Equipment
Siberian affiliate of Tekhenergokhimprom	Institute of Thermal Physics	USSR Ministry of Petroleum and Chemical Equipment
NII sistem	SOAN Computer Center and Institute for the Economics and Organization of Industrial Production	Dual subordination with the USSR Ministry of Instrumentation
KB of hydroimpulse technology	SOAN Institute gidrodinamiki	

[a]In addition, this institute appears to have dual-subordination design offices, but details are not available.

the SOAN institute, be studied and adopted elsewhere.[33] Another success story comes from the two KBs of the Institute of Thermal Physics, also established in 1972: High-quality cryovacuum technology, developed jointly by the institute and its KBs, is being marketed to key institutions like the Academy's Institute of High Temperature Physics and the Central Aviation Institutes.[34]

In general, however, it is hard to tell whether the MKOs are doing well or badly, partly because of the lack of reliable or revealing measures of output. For one observer, for example, the joint design bureau set up by the Institute of Catalysis and the USSR Ministry of the Chemical Industry is highly successful, because lead-times in projects in which the two institutions have been involved have been cut from 10-12 years to 3-4 years.[35] Yet for another observer, the Catalysis KB is one of the prominent examples of conflict and misunderstanding,[36] despite the fact that is conceded to have been an important agent in developing many of the more than fifty industrial catalysts introduced into industry by the Institute of Catalysis since the institute's creation.[37] From such comments, it is not really possible to tell where the balance lies.

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[33]Iu. E. Nesterikhin, "Dva desiatiletiia v sibirskom otdelenii AN SSSR," *Avtometriia,* No. 3, 1977, p. 4.
[34]"Akademiia-KB . . .," op. cit., p. 48. This is an especially valuable development, since vacuum technology has been a weak spot in Soviet science and technological development. See, for example, V. Reut, "Vokrug vakuuma," *Pravda,* April 20, 1977.
[35]Kushlin, op. cit., p. 164.
[36]Andreev, op. cit.
[37]Ibid.

The leaders of the Siberian Division are not particularly happy with the way the KBs have worked. Three main problems have emerged. First, since the ministries finance the KBs, they tend to give the orders. The then President of the SOAN, Academician G. I. Marchuk (now chairman of the State Committee for Science and Technology), had this to say in 1977:

> Originally it was supposed that the Academy would exert scientific leadership over the KBs, while administration leadership of development and production would be entrusted to the corresponding ministries. [But there has been] a clear tendency on the part of the ministries to subordinate these KBs entirely to the ministries' own tasks. . . .[38]

This, of course, is the opposite of what was supposed to happen, and in the eyes of the Academy, this kind of ministerial dictation robs the KBs of much of their justification. "You must agree," says a lab chief in the Institute of Catalysis, "the only sensible reason for their existence here is *us*."[39] Yet some of the managers of the KBs obviously feel differently. "Our only boss is the ministry," says the head of the joint KB associated with the Institute of Geology and Geophysics. "It gives us our money and lays down the plan."[40] The Academy scientists retort that the ministries are attempting to dictate to the Academy.[41]

This issue has led to steady skirmishing between the ministries and the Siberian Division, which continues to this day. But there have been some recent changes. The SKB on Catalysis, the SOAN and the Ministry of the Chemical Industry have negotiated a "charter," which defines in detail the rights and the responsibilities of the ministry and the Academy. Not more than one-third of the design bureau's projects may come from the ministry; the rest are specified by the Academy Institute. (Note that this refers only to the *number* of projects, not to their ruble amount. The difference could be important.) The charter has produced an uneasy peace, but Academy scientists evidently fear that it will not really solve the problem. The KB still tends to gravitate toward the ministry positions, if the institutes do not watch them carefully.[42]

The root of the problem apparently lies in the attitude of the *glavk* to which the KB is subordinated. In the case just mentioned, the leadership of the Ministry of the Chemical Industry is said to be sympathetic to what the Academy is trying to do, but the *glavk* in charge of day-to-day production and policy in catalysis, Soiuzkhimreaktiv, is not. As the responsible line organization, Soiuzkhimreaktiv has a plan to meet and constraints to wrestle with, which make it uncooperative. Until the charter was signed, it had been the habit of issuing emergency production assignments to the SKTB, throwing it into the breach to make up for any holdups elsewhere in the system, thus taking over a portion of the KB's capacity and personnel. The charter gives the Academy scientists a means of preventing this, but only if they are vigilant, because the *glavk,* after all, provides the financing.[43]

The second problem with the KBs is that they do not alleviate problems of innovation at later stages of the RD&D cycle, in particular the failure of ministries to cooperate with one another, to take responsibility for advanced engineering and pilot production, or to diffuse innovations once they have been successfully demonstrated at one or two enterprises. The head of the Special KB for Catalysis, for example, complains that the Academy scientists want him to work on catalysts for the petroleum refining industry, which he refuses to do because his

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[38]G. I. Marchuk, op. cit. (1977b), pp. 5-7.
[39]Andreev, op. cit.
[40]Ibid.
[41]Ibid.
[42]R. A. Buianov, "Ispytanie vremenem," *Ekonomika i Organizatsiia Promyshlennogo Proizvodstva,* No. 3, 1977, pp. 54-58.
[43]Ibid.

orders come from the chemical industry.[44] Any system that requires combining very different types of technologies, such as optics, microelectronics, and exotic metals, gets bogged down in endless interagency negotiations,[45] and on this point the KBs have been no help, since most of them are not equipped with facilities for pilot production.

Consequently, even the KB's successes have disturbing aspects, at least from the standpoint of the Academy. The Catalysis KB, for example, has helped set up a large industrial plant for the production of formalin with an annual capacity of 60,000 tons,[46] based on a catalyst developed at the Academy's Institute of Catalysis.[47] But though the plant is now on line, the ministry *glavk* cannot yet produce the catalyst on its own, and the KB is forced to continue supplying it. Academy scientists are concerned that sooner or later this will reduce the KB to the role of a mass producer of standard catalysts, rather than a proving ground for new ones.

Two of the most successful KBs are the pair attached to the Institute of Thermal Physics. The institute director, reflecting on the reasons for their good performance, ascribes it to the fact that the institute itself already had long experience in practical engineering, and therefore understood development problems. Moreover, in contrast to some other KBs, those of the Institute of Thermal Physics appear to be firmly under Academy control. Institute lab heads must approve each planned project before it goes to the KB's parent ministry for inclusion in the KB's official plan. The institute may owe its successful control to the fact that it started both KBs with a large number of its own people.[48]

Putting their own people into the KBs is one of the Siberian Division's main hopes for wresting de facto control of the KBs from the ministries. The strategy may be working. Academician Marchuk writes that:

> KB and SKB personnel are in constant contact with the scientists, participate in all our symposiums, conferences and advisory councils, and a strong mutual understanding, *often despite the will of ministry leaders,* tightly binds these new-style organizations to the Academy institutes.[49]

For example, one-third of the personnel of the Catalysis KB are transfers from the Academy's Institute of Catalysis.[50] This emphasis on the importance of training and personnel is characteristic of the Siberian Division, and reflects the strong imprint of its founder, Academician Lavrent'ev. Thus it is not surprising to find numerous statements by SOAN institute and lab heads about the key importance of *people* in technological innovation:

> Where we have people in industry who were trained by us, and where we create conditions under which industry is automatically staffed by our people, technology innovation happens more easily.[51]

> It is essential to create a continuous channel of interaction between science and production. The main thing in such a channel is not formal relations, but people-to-people contact . . . daily exchange of information, regular transfer of ideas. . . .[52]

[44] Andreev, op. cit.
[45] Nesterikhin, op. cit., 1975, pp. 53f.
[46] Formalin is a 37 percent aqueous solution of formaldehyde. The SOAN process bypasses the usual use of methanol as an intermediate. We are grateful to Professor Robert Minor of the Chemistry Department of Princeton University for a firsthand description of the Catalysis KB.
[47] Buianov, op. cit.
[48] "Akademiia-K.B.," op. cit., pp. 46-47.
[49] Marchuk, op. cit. (1977b), p. 10.
[50] Buianov, op. cit., p. 58.
[51] Nesterikhin, op. cit. (1975), p. 61.
[52] G. I. Marchuk, "Vykhod na otrasl'," *Literaturnaia Gazeta,* May 1, 1978b, p. 10.

Tension between the Academy and the industrial ministries over the joint KBs reflects the conviction of many Academy scientists that the main source of technological innovation is the basic scientist with a new idea, not the final user or manufacturer with a practical need. In the Soviet Union this is a deeply anchored conviction, caused mainly by the general resistance of users to innovation. Hence, one can understand the determination of the Siberian Division not to let the joint KBs be turned into ministry job shops. But there is the danger that, having recaptured the KBs, the SOAN scientists will find the gap between science and mass production as deep as before, for by its very success the Academy may only increase the indifference of the *glavki*.

Lately, the leadership of SOAN has taken a new tack, which indicates that they recognize this problem. Academician Marchuk has announced that henceforth the Siberian Division will enter into cooperative agreements with industry only on a *ministry-wide basis.* The Siberian Division will conclude a cooperative agreement with an industrial customer only if it is signed by a deputy minister or the minister himself. The Division has already concluded six such agreements with industrial ministries. They extend to five years and more, and contain clearly spelled-out obligations on both sides.[53]

Such agreements may have several advantages, if they work. First the Academy will be able to get materials and equipment for itself, some of which can then be used for basic research; this helps to relieve the chronic supply problem from which all basic research, even in the USSR Academy, typically suffers.[54] Second, if it is true, as some commentators say, that the higher ministry leadership is more sympathetic to technological innovation than the lower-ranking executives of *glavki,* then negotiating directly with the former will help to bypass problems the Siberian Division has encountered with the latter.

Another Experiment

The second experiment under way in the Siberian Division reflects a different diagnosis of the chief problems in Soviet RD&D management. The underlying theory behind the MKOs is that the main problem is organization and authority. Hence the creation of a new *organizational unit* under the control of the Academy institutes. The second experiment reflects the conviction that Academy researchers can do the job of innovation in cooperation with industry, if they are given the incentives to run the long gauntlet. Since 1972, by special decree of the State Committee on Science and Technology, the Siberian Division has experimented with a new incentive system. Confined for the moment to three institutes (the Institute of Mining Technology), the experimental incentive system aims at giving the institute a share in the economic benefits resulting from mass production of a new product or process. One of the ways this is done is by granting a mark-up on the wholesale price of a newly developed item, provided that it meets the highest quality standards—a device that has been used in the electrical-engineering reform, too.

Unfortunately, the Director of the Institute of Mining Technology gives the system low grades. Delays occur between the time an innovation is ready for demonstration and mass production and the time the mark-up is granted, and then the mark-up is only temporary.

[53] Marchuk, op. cit. (1977b), p. 9.
[54] Ibid.

(This may be a problem to watch for in the electrical-engineering reform.) Academy institutes (unlike ministry institutes) may not receive advances on the ultimate returns, and they find that their industrial partners cannot identify the additional profits due to any one innovation, are often slow about paying, or favor their own branch institutes over those of the Academy. About the only additional income received by the institute that turns out to be easily obtained and awardable to the basic science component of the institute is a small special surcharge on economic contracts. But for the Institute of Mining Technology, for example, this brings in only about 40,000 additional rubles out of the nearly one million rubles in contract business it performs each year. All in all, it seems that the aim of the experiment, to increase the incentive of the Academy scientists to take part in the rest of the RD&D cycle leading to mass production, has so far not been attained.[55] And judging from the relative publicity given to the two experiments, the economic-incentive idea has been pursued less enthusiastically by the leadership of the Siberian Division than the special KBs have. Recent articles by Marchuk hardly mention the former, but devote considerable attention to the latter. It is possible that the economic-incentive experiment did not originate with the Siberian Division and is not really supported by it. Certainly the idea of an "innovation belt" is much more in the spirit of the Siberian Division.

Appraisal and Conclusion: Is the Problem of Innovation in the Siberian Division Getting Better or Worse?

It is difficult to tell whether the problem of innovation has gotten better or worse in the years since the creation of the Siberian Division. Part of the problem is that writers on the subject make no allowance for the high percentage of failures inevitable in any process of technological innovation, or for the fact that many projects *should* fail, because they prove to be uneconomic. When a newspaper article observes disapprovingly that "40% of the projects of the Siberian Division are not successfully applied in production,"[56] it is clear that their expectations are excessive, and too technical-minded. An American vice-president for R&D of a major corporation would be delighted to be able to boast such a high statistic, provided those projects were actually moneymakers. In addition, there are problems of definition: We have no idea what Soviet commentators mean when they report a project as "unsuccessful." *At what stage* was it unsuccessful, and for what reasons? Finally, we lack any sense of the overall volume of the Siberian Division's effort in applied science and innovation; consequently, we cannot make much sense of statements about trends. We read that the rate of "unsuccessful innovation" in the Siberian Division has risen from 35 percent in 1962 to 40 percent in 1977.[57] Does this mean that the innovation problem has gotten worse? Or are the Siberians simply undertaking a larger number of applied projects?

The actual picture may be like this: (1) SOAN is under increasing pressure to do more applied research and development; (2) therefore the number of applied projects has grown; (3) but customers are only slightly more receptive than they were before; (4) therefore the percentage of "unsuccessful" projects goes up.

Whether this constitutes an improvement or a deterioration depends on your point of view. For the Presidium of the SOAN, it is undoubtedly a very grave problem. But for the American trying to appraise the effectiveness of Soviet R&D in the Siberian Division, there has not

[55] Shemiakin, op. cit.
[56] Andreev, op. cit.
[57] Ibid.

necessarily been any deterioration at all; despite the *relative* deterioration, the Siberian Division might be doing better in *absolute* terms, that is, in terms of the overall effectiveness and sophistication of its contribution to technological innovation. Perhaps a better indicator for the foreign observer is the number of foreign patents and licenses held by the Siberian Division: As of the middle 1970s, the Siberian Division held foreign patents on over 100 products and processes, and had concluded ten license agreements with foreign companies, and five options. Four out of those ten covered a single process for centrifugal refinement of tin ore developed by the Institute of Hydrodynamics.[58] The Siberian Division also sells its developments abroad directly, for example, a highly successful small-bore pneumatic drilling machine,[59] developed by the Institute of Mining.

NEW MANAGEMENT EXPERIMENTS IN THE UKRAINIAN ACADEMY

Both the volume and distribution of funding in the Ukrainian Academy of Sciences are very different from the Siberian Division, and the result is a very different type of involvement in applied research and development. First, like many of the republican academies, the Ukrainian Academy has expanded rapidly since the early 1960s. Total funding nearly quadrupled between 1962 and 1975. But much of this increase has come from contracts. The share of the Ukrainian Academy's funding from this source has far outstripped the portion that comes from direct central-budget funding. From a level of 16.5 percent in 1962, contract funding increased nearly ninefold by 1975, and in that year amounted to 38 percent of the Ukrainian Academy's total allocation.[60] Thus it is very clear that the Ukrainian Academy is nearly twice as dependent on industrial customers as the Siberian Division is, and that its involvement with industry is increasing much more rapidly than it is in Siberia. What are the implications of these facts? First, it is not clear to what extent the Ukrainian Academy actively desired such an extensive involvement with industry, and to what extent it has been pushed into it by the Ukrainian government and the leadership of the USSR Academy in Moscow. A recent article by A. Liashko, the Ukrainian Prime Minister, stresses the importance of targeting research toward near-term results in production.[61] "Top priority must go to research that ensures growth in the efficiency of production in the present five-year plan and in the near term. . . ."

As for the central USSR Academy, it has forced the Ukrainians to turn to industrial contracts by gradually cutting down on the flow of supplies, equipment, and instrumentation from the central Academy to the Ukrainian Academy.[62] The result has been to throw the Ukrainian Academy back on its own resources to a much greater degree than the Siberian Division. Finally, the State Committee on Science and Technology has had some part in the Academy's growing dependence on contracts, since it has used 37 million rubles of its reserve funds during the early 1970s to finance "supplementary topics."[63] This amounts to about 7.5 percent of the Ukrainian Academy's total contract business during the Ninth Plan (1971-75).

Whether the Ukrainian Academy welcomes such a heavy dependence on contract funding

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[58]Marchuk, op. cit. (1977a), p. 38.

[59]Shemiakin, op. cit., pp. 63-64.

[60]B. E. Paton, "Effektivnost' nauchnykh issledovanii i uskorenie protsessa vnedreniia," *Vestnik AN SSSR*, No. 3, 1977, pp. 43-58; and B. E. Paton, "Nerazryvnoe edinstvo nauki i proizvodstva," *Ekonomika i Organizatsiia Promyshlennogo Proizvodstva*, No. 5, 1973, pp. 3-13.

[61]A. Liashko, "Plodotvornyi soiuz nauki i proizvodstva," *Pravda*, February 7, 1978.

[62]A. A. Savel'ev, V. A. Iakovlev, "Osnashchennost' sredstvami eksperimenta—faktor intensifikatsii issledovanii," *Naukovedenie i Informatika*, No. 16, 1976, pp. 86-96.

[63]Paton, op. cit. (1977).

is unclear. The President of the Ukrainian Academy, Academician B. E. Paton, is simultaneously director of the prestigious Institute of Electro-Welding, and stands as a symbol throughout the Soviet Union of the successful blending of theoretical research with applications to industrial production. I have no exact figures on what percentage of the Electro-Welding Institute's income stems from industrial contracts, but it is conceivable that it reaches as high as 70 percent.[64] Yet Paton himself has stated on occasion that the maximum desirable proportion of contract funding for the Ukrainian Academy should be no higher than 50 percent for any one institute and 30 percent for the Academy as a whole,[65] lest the Academy institutes be transformed into "branch organizations," i.e., ministry institutes.

It should be noted that Paton's reservations concern the mechanism of funding, not the relative weight of basic and applied research. His concern is to avoid an excessive dependence on contracts. Marchuk, on the other hand, wishes to avoid an excessive involvement in applied research and development. This is one important difference between the Ukrainian Academy and the Siberian Division.

Many of the arrangements developed recently in the Ukrainian Academy are much the same as those of the Siberian Division. Like the latter, the Ukrainian Academy has its industry-wide agreements with various ministries, locates new centers and affiliates in growth areas of industry (although it tends to locate them in established ones like the Donbas, rather than areas of future growth as SOAN does), and it operates dually subordinated development "bureaus," financed by industrial ministries but working on products and processes that come from the Institutes of the Academy.

An important difference is that the Ukrainian Academy takes the innovation process one or two steps further along toward mass production. It often does pilot production and demonstration, and some of its joint bureaus act as advisers in the construction of new factories and factory divisions (*tsekhi*). In a couple of instances, an institute of the Ukrainian Academy has official status as the lead institute for its specialty for the entire country. This is true of the Paton Institute, and also of the Institute of Problems of Materials Science, which acts as the country's lead institute for powder metallurgy.[66]

To a much greater extent than the Siberian Division, the Ukrainians have used the device of "branch laboratories," that is, laboratories belonging to industrial ministries but located in the Academy institutes. Toward the end of 1976, there were 26 such laboratories, notably in the Institute of Cybernetics, the Semiconductor Institute (five laboratories). The first of these go back to 1970 (Institute of Physics' laboratory for microelectronics).[67]

That the Ukrainian Academy is much more heavily involved in the later stages of the RD&D cycle is strikingly illustrated by the fact that in at least two cases the Siberian Division has turned to the Ukrainian Academy to take over key projects and bring them to mass production through their own facilities and relations.[68] The Paton Institute has helped in setting up applications of explosion-welding technology, and the Semiconductor Institute, through a joint optical electronics lab that it runs together with the "Tochelektropribor" factory, has put into production current-measurement devices invented by the SOAN Institute of Automatic Systems and Electrometry.

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[64] The basis for this guess is that Paton's Institute is located in a section of the Academy—the Section of Engineering Physics and Mathematical Sciences—which averages 48 percent contract financing, and resembles (in its degree of involvement with industry) other institutes like the Institute of Super-Hard Materials that are known to have contract financing at a level around 70 percent. Source: Paton, op. cit. (1977).

[65] Paton, op. cit. (1973), and Paton, op. cit. (1977).

[66] "Detal' iz poroshka," *Pravda,* July 28, 1978.

[67] Paton, op. cit. (1977).

[68] Trefilov, op. cit.

Lately, the Ukrainian Academy has developed its own unique arrangement: associations comprising an Academy institute, a joint development bureau, and a factory specializing in pilot production. This package, called a *kompleks,* has been praised throughout the Soviet press and held up as a model for all the republican academies to follow.[69] The chief drawback of the *kompleks,* as the Siberians might have predicted, is that since the various units belong to different organizations it has been difficult to have them operate together. Consequently, the most recent move has been to amalgamate the units into an official legal entity, called a scientific-technical association (*nauchno-tekhnicheskoe ob"edinenie,* or NTO).

What is the difference between an NTO and an NPO? Paton and one of his vice-presidents seem to have some difference of opinion on this point. According to Paton, the chief difference is that an NPO actually takes a new process or product through the stage of mass production, while an NTO stops short of mass production. However, V. Trefilov, vice-president of the Academy, speaks of the production facilities of the NTOs as a sort of *innovation reserve* for high-priority projects, that will assure output until regular mass production can be started up. The *kompleksy,* he writes, are the "prototype of a system of reserve productive capacity." Language such as this appears to put the Ukrainian Academy fully into mass production. The example of the Paton Institute is being extended to five other institutes, and these in turn are to serve as models for institutes in many of the other republican academies.[70]

The five NTOs developed by the Ukrainians are focused on some of the most advanced technologies, some with potential military uses: superhard materials, materials sciences, high-performance alloys, low temperatures. In the Siberian Division this is not so clearly the case, although the technologies involved are certainly important (catalysis, mining technology, uses of low-grade heat). The only two Siberian MKOs of unambiguously high-technology significance are the one for computerized management systems (*NII Sistem* attached to the SOAN Computer Center) and the joint facility for scientific instruments, attached to Nesterikhin's institute.

CHECKLIST OF DIFFERENCES BETWEEN THE SIBERIAN DIVISION AND THE UKRAINIAN ACADEMY

There appear to be several important differences between the management experiments being pursued by the Ukrainian Academy and those of the Siberian Division.

For one thing, the Ukrainian Division has gone much further in setting up test and pilot-production facilities, *opytno-eksperimental'naia baza,* whereas the Siberian Division seems to have stopped short of that, except in the case of the manufacture of scientific instrumentation. As of early 1977, the Ukrainian Academy had four plants (*zavody*), 29 pilot plants and 18 KBs and five computer centers.[71]

Second, these Ukrainian operations in applied science and development appear to involve much larger sums of money than those of the Siberian Academy. Assuming that SOAN institutes do an average of one million rubles apiece of *khozdogovor* business, that would amount at most to some 40 million rubles annually for SOAN as a whole—and that is probably a generous estimate. The Ukrainian Academy does an annual total of 100 million rubles of

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[69]"Sviaz' nauki i praktiki: zadachi respublikanskikh akademii," *Vestnik Akademii Nauk,* No. 8, 1977, pp. 11-27.
[70]Trefilov, op. cit.
[71]Ibid.

business in experimental production alone—and that presumably does not include the additional amount done by contract in its regular institutes.

Third, the model being proposed to the other republican academies for emulation is the Ukrainian Academy, not the Siberian Division. This is consistent with the difference between the general orientation of SOAN and that of the Ukrainian Academy: The first is part of the central Academy, and therefore somewhat more oriented toward basic research and less involved with industry. The Ukrainian Academy, like most of the republican academies, has long been more oriented toward industry. Finally, the extent of involvement of the Ukrainian Academy in applied research and development has increased much more rapidly in the last few years than has that of the Siberian Division.

Appendix to Part VI

APPLIED-RESEARCH CONTRACTS IN THE ACADEMY SYSTEM

To attempt to bring the basic-research institutes into closer touch with those who might apply their work, the Soviets have experimented with a new system of direct contracts, called *khoziaistvennye dogovora*. Their importance in the funding of the Academy's research is growing rapidly; as of the mid-1970s, they accounted for 12 percent of the overall resources of the USSR Academy (excluding capital construction). In the republican academies and the Siberian Division, the share of *khozdogovora* is higher still. Such contracts offer special inducements to the institutes: up to 6 percent of the salary component of the contract can be used for bonuses (in contrast to 1½ of the customary state-budget funding from the Academy), and the rest can be used for any purpose save the hiring of additional personnel.[1] Consequently, this is a convenient way for institutes to pay for additional supplies and equipment. Many USSR Academy institutes now do a sizable part of their work on a *khozdogovor* basis with branch customers:

Institute of General and Inorganic Chemistry	15%
Institute of Elemento-Organic Compounds	10%
Institute of Chemical Physics	15%
Computer Center of the Siberian Division	50%
SO Institute of Automatic Systems and Electrometry (counting the RB)	25%
SO Institute of Economics	25%

There is some evidence that the Academy tries to limit the impact of *khozdogovora* on what it considers to be its main function—basic research. According to Academician Zhavoronkov, the Presidium of the Academy has set a guideline that institutes should not do more than 25 percent of their work on *khozdogovora*, although the impression received from interviews everywhere was that industrial customers were practically pounding at the doors of the institutes. But the final decision on the *khozdogovor* level is apparently left to the institute director.

The distribution of *khozdogovora* within institutes suggests a desire on the part of the directors to concentrate them in one or two laboratories, generating income for the institute while leaving the other laboratories free to concentrate on basic research. Thus, in the Institute of General and Inorganic Chemistry, one-third of the *khozdogovor* work is devoted to growing crystals for outside customers. At the Institute for Elemento-Organic Compounds, much of the *khozdogovor* work takes place in the section on high polymers. A similar pattern can be seen in the Siberian Division: Whereas the average amount of work funded by *khozdogovora* for the SOAN as a whole is 25 percent, the highest concentrations are in the institutes with obvious relevance to industrial applications, such as the SOAN Computer Center.

[1]Kushlin, op. cit., p. 138. In the Siberian Division, the share of *khozdogovoza* grew from 6 percent in 1965 to 20 percent in 1975. And in the Ukrainian Academy, it grew from 16.5 percent in 1962 to 24.8 percent in 1971. The rate of increase of *khozdogovora* in the Ukrainian Academy far outstripped the growth rate of central budget funding: 4.3 times vs. 2.57 times during this period. (Savel'ev and Iakolev, op. cit., p. 88.)

VII. CONCLUSIONS

The aim of this report has been to contribute to the current rethinking of American policy on technology transfer to the Soviet Union by discussing on the implications of recent Soviet efforts to improve their own technological innovation. We wish to know whether these efforts have altered the technological transfer problem, by improving the ability of the Soviets to profit from foreign technology by using it to generate and diffuse further advances of their own. In this concluding section we summarize our findings and draw out their chief implications, together with some recommendations for American policy.

First, what exactly is at issue? No one in the United States questions the need to control exports of direct military importance. To the extent that American security continues to rest on a lead in critical military technologies, then safeguarding technological lead-times is in the nation's vital interest. Something like the present system of case-by-case evaluation, aimed at preventing clear and immediate military use of American technology by the Soviets, must and undoubtedly will continue.

Rather, the issue today is what to do about the possibility that the United States is giving away indirect military advantages through subtle channels that may call for more subtle defenses. The main danger is not so much the possibility of sudden and disastrous give-aways, but rather that high-technology trade may help the Soviets to upgrade over the longer term the traditionally neglected "civilian" industries that will provide broad, infrastructural support for new weapons systems tomorrow. Some of the most significant obstacles to Soviet military progress come from deficiencies in the civilian sector (for example, computers, communications, energy, and new materials), and this drag can only increase in the future, as military development comes to depend more and more intimately on the combined technological skills of a nation's entire industry. But does foreign technology really enable the Soviets to overcome those obstacles, and could an expanded system of export controls prevent them from doing so?

The major weakness of the present system of controls, in the view of some of its critics, is that it allows important technology to slip through to our military competitors by paying too much attention to the export of products, and not enough to the control of skills, techniques, and know-how. Consequently the most recent U.S. legislation mandates the development of a review procedure that will control classes of critical technologies rather than individual products. Recent American thinking focuses particularly on "active" mechanisms of transfer, such as training agreements, long-term technical exchanges, extended workshops, and other apprenticeship-like arrangements that teach skills and know-how.[1]

It is important to explore carefully the implications of such a broadening, because it can lead to excesses. A recent example that gives food for thought is the decision made at the beginning of 1980 to bar Soviet representatives from attending two technical conferences in the United States—one on bubble memories and the other on laser fusion—in order to prevent transfer of the knowledge discussed there. The two meetings involved technical data directly related to development and manufacture; therefore the Department of Commerce held that the participation of the Soviets required a license, which the Department chose to deny. Other

[1]U.S. Congress, Public Law 96-72, Export Administration Act of 1972, September 29, 1979.

foreign delegates were asked to sign pledges that they would not reveal what they had learned at the meetings to colleagues from communist-controlled countries.[2]

This episode suggests what a broadened export-control doctrine could lead to: First, it tempts us to put pressure on allied governments and their citizens, to induce them to cooperate with our expanded export-control program, despite the fact that support for export controls has been declining abroad.[3] The Carter Administration experimented with economic reprisals against the French firm Creusot-Loire for concluding a contract with the Soviet Union that Washington disapproved of; and the logic of the critical-technologies approach, if we mean to apply it seriously, will lead us toward more measures of the same kind.

Second, the attempt to control "active" mechanisms of technology transfer may inhibit unimpeded and rapid international communication of technical skills and information, at a time when the United States is moving from the position of a dominant supplier of leading technology to that of a beneficiary of foreign advances, and is therefore increasingly dependent upon free exchange. Unless we are judicious about them, expanded export controls could cost us considerable good will among important commercial partners in the West.

To put these points in perspective, it is worth bearing in mind that in the total volume of Western high-technology exports to the Soviet Union the United States is a small player. American high-technology exports to the Soviet Union in 1979 amounted to $183 million ($270 million to Eastern Europe as a whole), about one-tenth the level of Soviet imports of advanced machinery and equipment from West Germany, France, and Japan combined (see Table 5). Direct scientific contact is also quite small. The 13 U.S.-Soviet bilateral agreements, at their height, involved little more than 1000 people from each side each year, most of them on carefully orchestrated and necessarily superficial two-week visits. The scientific exchange program conducted by the two countries' Academies of Sciences supports fewer than 250 man-months of visits from each side, few of them involving actual research.[4] Moreover, it is unlikely that extension of most-favored nation treatment and credits by the United States would change this situation much, because the Soviets have taken some care throughout the 1970s to diversify their sources of supply and to limit their indebtedness (see Table 6).

In view of these modest dimensions, it is clear that the effect of whatever policy the United States pursues will be slight compared to the actions of our principal allies, and slight also in its overall effect on Soviet science and technology, given how little actual contact there is between the two countries. The chances of gaining much support from other countries are small and growing smaller, for among the nations conducting high-technology trade with the Soviet Union one finds not only NATO allies (whose reluctance to apply stiffer export controls is of long standing), but also countries like Austria and Switzerland, which are unlikely to co-operate at all.

Consequently we should not imagine that an expansion of export controls would be free of

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[2]Nicholas Wade, "Science Meetings Catch the U.S.-Soviet Chill," *Science*, Vol. 207, March 7, 1980, pp. 1056-1058.

[3]For a recent report, see Angela Stent Yergin, *East-West Technology Transfer: European Perspectives*, The Washington Papers, No. 75, Sage Publications, Beverly Hills, California, 1980.

[4]The basis for the expanded exchanges of the 1970s was a series of eleven agreements signed by the American and Soviet governments between May 1972 and June 1974, which increased tenfold the volume of technical visits between the United States and the Soviet Union. For descriptions and evaluations, see Lawrence H. Theriot, "Governmental and Private Industry Cooperation with the Soviet Union in the Fields of Science and Technology," in U.S. Congress, Joint Economic Committee, *Soviet Economy in a New Perspective*, U.S. Government Printing Office, Washington, D.C., 1976, pp. 753-755; National Academy of Sciences, National Research Council, *Review of the US/USSR Agreement on Cooperation in the Fields of Science and Technology*, Washington, D.C., 1977; and Loren R. Graham, "How Valuable Are Scientific Exchanges with the Soviet Union?," *Science*, Vol. 202, October 27, 1978, pp. 383-390; see also Francis W. Rushing and Catherine P. Ailes, "An Assessment of the USSR-US Scientific and Technical Exchange Programs," in U.S. Congress, Joint Economic Committee, *Soviet Economy in a Time of Change*, Vol. II, U.S. Government Printing Office, Washington, D.C., 1979, pp. 605-624.

Table 5

Soviet Imports of Western Technology[a]

Index No.	Class of Import	USA 1977/1978	West Germany 1977/1978	Japan 1977/1978	France 1977/1978
10	Machinery, equipment, and transportation	351/273.5	1041.5/1004	685/830	566.5/688
100-103	Metal-cutting and shaping, and fabrication	17/11	154/157	21/46	9/14
10515 110-111 113	Electrical and power engineering equipment and manufacturing facilities for same		14/12	11/18	30/23.5
12303	Metal rolling equipment	0.5	68.5/101	3.5/43	20.5/11.5
127	Petroleum—refining equipment			25.5/157	3.5/29.5
128	Drilling, extraction, and exploration	21/38	15/10		12/0.5
150	Chemical-industry equipment	113/42.5	274/238	286/233	350.5/406
154	Road-building	30.5/53		17.5/34	
15501	Pumps	17/7	11.5/9	7.5/2	1/1.5
15931	Computers	8.5/25		2/1	2.5/4
15932					
15941					
170-171 178-179	Instruments and lab equipment	8/8	17/12	12/10.5	8/10.5

SOURCE: *Vneshniaia torgovlia SSSR v 1978g.: statisticheskii sbornik*, "Statistika," Moscow, 1978.
[a]In 10^6 rubles, rounded to the nearest half million.

Table 6

Soviet Imports of Metalworking Machinery and Equipment

	Value (in thousands of rubles)								
Exports	1970	1971	1972	1973	1974	1975	1976	1977	1978
Total	425,311	294,434	430,264	589,561	747,986	941,358	976,316	1,059,025	1,055,618
From Developed West	315,967	155,303	231,389	360,083	489,855	593,797	582,337	557,164	474,475
F.R.G.	65,733	39,290	90,355	126,491	185,522	203,968	240,288	230,228	182,916
U.K.	25,498	17,282	23,394	32,929	10,567	23,199	22,805	8,790	29,400
U.S.A.	11,534	10,039	20,480	51,495	55,439	91,318	71,064	34,205	17,491
	Shares (in percent)								
DW of Total	74.3	52.7	53.8	61.1	65.5	63.1	59.6	52.6	44.9
F.R.G. of DW	20.8	25.3	39.0	35.4	37.9	34.3	41.3	41.3	38.6
U.K. of DW	8.1	11.1	10.1	9.1	2.2	3.9	3.9	1.6	6.2
U.S. of DW	3.7	6.5	8.9	14.3	11.3	15.4	12.2	6.1	3.7

SOURCE: Soviet trade handbook—*Vneshniaia torgovlia SSSR*, 1970-1978.

serious political costs; indeed, it might be unenforceable at any cost. Before we make the attempt, therefore, we should be clear on whether technology transfer actually has the effects we fear and whether expanded export controls would make a substantial difference. Hence the emphasis of this report on the environment in which exported technology is received. We turn now to a summary of our essential findings.

Broadly speaking, in the last decade the Soviets have pursued two strategies simultaneously to improve the technological level of their economy. The first is a "quick fix" approach, aimed at modernizing backward branches of industry quickly through large-scale imports of foreign equipment and plant. In certain industries, notably those which manufacture chemical equipment, agricultural technology, automobiles, machine tools, precision instruments, and pipeline and drilling equipment, the Soviets have relied on Western suppliers for a large part—in some cases the virtual entirety—of new productive capacity. The industries involved here have been a varied lot, and in no two cases has Western technology played exactly the same role. However, two general traits appear to hold for most of them:

- The resort to massive imports has come suddenly each time, as a result of ad hoc political decisions to upgrade the priority of the industry concerned (e.g., the "chemicalization" campaign under Khrushchev). Therefore the turn to Western technology in such cases is only partly the result of the inability of the industry to respond to sudden demands placed upon it (e.g., to increase the output capacity of fertilizer from 10 to 100 million tons in one five-year period, or more recently, to expand the output of light automobiles beyond one million new cars a year). The possibility of turning to foreign suppliers has given Soviet leaders a freedom for rapid maneuver that the rigidity of Soviet economy denies them.
- The quick-fix import programs rely on import of finished products above all, such as complete plants and heavy equipment. And while considerable training and demonstration are involved, they are centered primarily on the management of well-established technology, i.e., that embodied in the finished product, rather than the transfer of skills that confer the ability to generate further innovation or diffuse the acquired technology rapidly.

These two features have implications that we shall return to below.

The second principal strategy is internal reform of the management of technological innovation. Though less spectacular than the first strategy, it is potentially further-reaching, since it is aimed at the root causes of Soviet backwardness. Soviet literature on technological innovation goes back more than fifty years, pointing to many of the same problems and complaints as today, but the last ten years have witnessed an unprecedented degree of soul-searching and experimentation on the part of Soviet officials and experts at all levels. Such efforts testify to a growing Soviet recognition that their traditional approach to promoting economic growth and higher productivity is no longer adequate.

The crucial instrument in that traditional approach is the selective allocation of priority. For military purposes, for example, two principal techniques have long been used to secure scarce resources and manpower: a Manhattan-Project style of organization for large, high-priority ventures, combined with a systematic skimming of the highest-quality output from ordinary producers throughout the economy, by means of ubiquitous "military representatives" (*voenpredy*) stationed in factories in every industry, armed with the authority to select and commandeer output that meets the military's requirements. By means of such devices, the Soviets are able to concentrate effort, materials, and skills on the most important projects related to national security and other top priorities.

However, priority is by definition a scarce resource. There is evidence that some dilution of its effects has already occurred in the last two decades, as a result of the need to bring an ever-broader array of industries and technologies into play with each new generation of weaponry.[5] But priority that is no longer priority becomes meaningless, and attempting to spread it thinner is no substitute for thorough-going reform in the incentives and organization for innovation. Indeed, military-related industries themselves have pioneered many such devices and they are now being extended to important civilian industries. One way of looking at recent Soviet experiments in technology policy is to consider them a wager on the Soviets' part that management devices perfected under high priority will yield good effects when applied where priority is lower.

Throughout the Soviet period there has been an uneasy coexistence between foreign imports and home-grown enterprise (the latter usually entailing some degree of reform) as the two principal strategies for technological innovation, the former predominating in some periods (such as the First Five-Year Plan, 1928-1932) and the latter in others (such as the Second Five-Year Plan, 1933-1937). Logically, the two strategies should complement one another; but in practice they have tended to compete, and the balance between them swings with the state of mind of the Politburo, from emphasis on independence to emphasis on fast catch-up, and back again.[6] The last fifteen years have been somewhat exceptional, for both strategies have been pursued simultaneously, and more vigorously than ever before.

The simultaneous existence of these two strategies raises a number of questions. First, to what extent are they connected, that is, does a crash program of Western imports involve at the same time a reform of the management of innovation in the industry involved? Do recent Soviet experiments in the management of innovation make the Soviets better able to profit from transferred technology? Are the Soviet experiments in the management of innovation themselves a species of "higher-level" technology transfer, which might be prevented or regulated? What do Soviet problems with both strategies reveal about the root causes of Soviet lag in technological innovation, and what further guidance do they give us about appropriate policies for technology transfer? The findings of this report suggest some preliminary answers:

1. *Recent Soviet reforms in the management of technology are only distantly inspired by or related to Western technology as such.*

In Soviet writings one can see evidence of a limited "transfer" of Western thinking about the management of R&D and innovation, and in particular, some effort to learn from American methods. Soviet specialists on the United States have devoted considerable attention to the American system of R&D policy and administration, focusing notably on issues that are known to be of special concern in the Soviet Union (such as contracts, research parks, or the structure of research corporations).[7] We can tell that some of this knowledge actually finds its way to policymakers because American management methods have been copied in the Soviet space and military programs.[8]

On a broader plane, there has been a fashion in Moscow for Western management theory and Western-style computerization of management processes. Not only has Western management literature influenced a whole generation of Soviet management specialists, but through exchange programs and bilateral cooperation (as well as joint creations like the International

[5]For an interesting account of this phenomenon in military-sponsored Soviet work in radiolocation, see A. Fedoseev, *Zapadnia: Chelovek i sotsializm*, Possev, 1977.

[6]See Bruce Parrott's excellent description of this ambivalence in official Soviet policy in his forthcoming book, M.I.T. Press, 1981.

[7]See Thane Gustafson, "American Science Policy Through Soviet Eyes: A Reflection of Soviet Concerns and Priorities," in John R. Thomas and Ursula M. Kruse-Vaucienne, eds., *Soviet Science and Technology: Domestic and Foreign Perspectives*, The George Washington University, Washington, D.C., 1977, pp. 83-100.

[8]Campbell, op. cit., pp. 586-607.

Institute for Applied Systems Analysis), the Soviets are being exposed directly to Western techniques. They have based their own systems of management education on American models, notably the case method of the Harvard Business School. It is uncertain as yet how much actual change has been wrought by this movement, but it is undoubtedly a leaven in Soviet thinking about industrial productivity.[9]

These Western examples, however, have had only marginal effects on the reform effort as a whole. The Soviet experiments we have discussed in this report are primarily Soviet in inspiration, modeled on Soviet antecedents, and addressed to characteristically Soviet problems. The defects they are aimed at arise out of the Soviet system of planning and organization, and consequently address specifically Soviet worries about incentives, information flow, financing, priority-setting, coordination,[10] and failure of effective demand for innovation. That these problems are systemic, i.e., generated by the Soviet economic and political system, can be seen from the fact that much the same issues and problems have been stock concerns in Soviet science-policy literature ever since the first Five-Year Plans.[11]

2. *Soviet crash imports and internal management reform do not appear to be directly related or mutually reinforcing.*

There is only a very partial overlap between the "long-term" reforms discussed in this report and the "quick-fix" import programs. The massive import of Western equipment is not usually accompanied in the same industry by a massive program to change management of innovation, and there is little apparent effort to exploit the synergistic effects that presumably exist when massive technology imports and internal management reform occur together. It is as though the two types of moves were decided upon independently, by different kinds of people. Most of the recent imports of Western technology, as already mentioned, have been concentrated in chemical equipment, machine tools, automotive manufacture, agricultural equipment and, increasingly, in extraction and transmission of oil and gas. These are not, by and large, the ministries that have made the most highly publicized efforts to reform the management of technological innovation.[12] The main exceptions to this observation are the computer and instruments industries, to which we shall return below.

Why has there not been a better "fit" between the two strategies? For the moment we can only speculate. First, they address different problems in different time-frames. The attraction of massive imports is that they promise to be fast and simple, conferring quickly the capability to get an important job done. The Academy of Sciences, for example, has recently imported a lot of advanced Western instrumentation to improve Soviet performance in biochemistry and molecular biology, once-neglected subjects that have been promoted to top priority recently because of the possible industrial applications of genetic engineering. At the same time, the Academy has created special instrumentation associations to produce advanced equipment at home. The latter effort will take years, but in the meantime, thanks to imported instruments, the Soviets are making rapid strides in the life sciences. In this case (one of the few in which

[9]One of the most important vehicles for this kind of "transfer" is the monthly journal of the Institute for Economics of Industrial Production of the Siberian Division of the USSR Academy of Sciences, *Ekonomika i Organizatsiia Ekonomicheskogo Proizvodstva* (often referred to as "EKO").

[10]See Berliner, op. cit.

[11]For a discussion that illustrates this point strikingly, see Robert Lewis, *Science and Industrialization in the USSR: Industrial Research and Development 1917-1940,* Holmes and Meier Publishers, New York, 1979. It is remarkable how many of the complaints, as well as the proposed solutions, are the same from the 1930s down to the present day. For comparison, see Organization for Economic Cooperation and Development, *Science Policy in the USSR,* Paris, 1969.

[12]That is not to say that some overlap does not exist. The Ministry for Petrochemical Machine-Building (Minneftekhimmash), which imports large quantities of shipment from the West, has pioneered a general-contractor approach to supplying equipment to new plants. The Ministry of Agricultural Machine-Building (Minsel'khozmash) has experimented with a new approach to demand and has learned much from its export activities. (We are indebted to Nancy Nimitz for these observations.)

foreign imports and domestic management reform are clearly occurring simultaneously), the difference between the two approaches is manifest: Foreign imports provide for the present and management changes provide for the future (so their originators hope).

The difference in time-frames between the Western-import and management-reform strategies may, in turn, spell further differences, notably in the kinds of people and organizations associated with each. The State Committee on Science and Technology, for example, is heavily involved in both imports and reform, but each strategy is presumably handled by different divisions, imports by the "branch" divisions that correspond to each of the major branches of industry and agriculture, and management reforms by the "functional" divisions that focus on matters such as the economics and organization of research and innovation.[13]

To be sure, there is one mechanism, not yet discussed in this report, that gives the State Committee, at least on paper, the potential for uniting the import and management-reform strategies. This is the system of "integrated programs" (*kompleksnye programmy*), a list of 200-odd high-priority "problems" established and overseen by the State Committee on Science and Technology. Each one encompasses the entire R&D cycle from basic research to final application in production. Together they cover one quarter of the total budget for research and development of the country.[14] The "problems" are clearly of great potential importance as a management mechanism, for in addition to providing continuity from one stage to another in the R&D cycle, they afford the possibility, in principle at least, of systematically combining imported technology with internal changes. But it is not certain how effective the integrated programs have been in practice, because the influence of the State Committee over the ministries and their institutes appears weak, its control over funding and other resources is slight,[15] and its own internal organization may discourage a truly integrated approach.[16] Its influence over the trading organizations of the Ministry of Foreign Trade is equally uncertain.

The apparent failure to coordinate foreign imports and internal reform may involve a question of risk: Foreign technology, at least, has proved itself and is known to produce predictable results. Management reforms, if they produce results at all, are hard to measure, unpredictable in their effects, and probably slow to pay off. Soviet decisionmakers, in the short term, may place more confidence in the import strategy than in the management reform strategy. In essence, massive imports may be viewed as an extension of the "priority" method, that is, concentrating scarce resources on a need rather than implementing reforms to eliminate or alleviate the underlying problems.

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[13]The State Committee on Science and Technology has an unusual administrative structure that may be designed to prevent a separation between the "branch" and "functional" activities of the committee: Each deputy chairman is in charge of some of both kinds. For example, Deputy Chairman M. G. Kruglov oversees both the Instrument Making and Radio Electronics Directorate (Chief: A. P. Yurkevich) and the Organizations and Economics of Scientific and Technical Research Department (Chief: V. A. Pokrovskii).

[14]S. Tikhomirov, op. cit. (1978b). For a lengthier description of the functions and powers of the State Committee on Science and Technology (unfortunately somewhat out of date), see *Organizatsionno-pravovye voprosy rukovodstva nauki v SSSR*, "Nauka," Moscow, pp. 158-169. This section, by G. A. Dorokhova, tends to be somewhat skeptical about GKNT's actual powers and effectiveness.

[15]Academician Paton, for example, gives the impression that the funding role of the State Committee is to supplement that of regular sources of support, by commissioning "supplementary" research themes, presumably ones that fit the overall programs. But such supplementary funding appears modest, in comparison with "mainline" sources of support. For example, according to Paton, the State committee funded 37 million rubles' worth of R&D in the Ukrainian Academy of Sciences during the period 1971-75, spread out over 354 projects. That makes an average of about 20,000 rubles per project per year, certainly not a crucial increment. Paton, op. cit. (1977), p. 50. As for GKNT's power to reassign funding among participating ministries, it requires the ministries' consent, and is therefore presumably requested only with diplomacy and circumspection. *Organizatsionno-pravovye voprosy rukovodstva naukoi v SSSR*, op. cit., p. 124.

[16]According to an article by the Minister of Nonferrous Industry, P. F. Lomako, the State Committee on Science and Technology is hindered in overseeing any project that involves more than one branch of industry, because it is excessively narrowly structured by branch. P. F. Lomako, "Faktor vremeni," *Trud*, February 1, 1975.

The tenuousness of the connection between foreign technology transfer and internal reform must not be overstated. One can find examples of apparent ties between the two, such as the collaboration of NPO Plastpolimer with East German chemical engineers in launching the "Polymer 50" complex in Novopolotsk, or the interaction of "lead institutes" like the Paton Institute (electrowelding) or "production associations" like Elektrosila (heavy electrical equipment) with Western technologists (although we should bear in mind that all three of the organizations just named are long-standing and prestigious establishments despite their "new" labels, and as such more properly belong to Conclusion 4 below). Nevertheless, even in such cases one can trace no obvious synergistic effects coming directly from the simultaneous presence of foreign transfers and changes in the management of innovation.

The above is not meant to imply that Soviet leaders do not take reform of technological innovation seriously; on the contrary, it is clearly one of their dominant concerns. Rather, what lies behind all the possible explanations we have just enumerated is the plain fact that internal reform, since it involves changing basic incentives and patterns of communication throughout the industrial system, is a daunting proposition. Imported technology, on the other hand, does not require overhauling the economic system in order to put it to work. But as a consequence, the contribution of Western technology to Soviet innovative abilities is considerably diminished. The history of technological innovation and diffusion in the last two centuries teaches the importance of foreign example and instruction—but only if, at the same time, the political and economic institutions of the receiving country adjust accordingly.[17]

3. *Imports by themselves do not enable the Soviets to overcome dependence, but may actually increase it.*

The examples of the Soviet chemical and machine-tool industries, discussed in earlier sections, suggest that massive Western imports by themselves do not give the Soviets a capability for generating their own advances. Western imports have not compensated for these weaknesses; if anything, imports may have contributed to perpetuating them, by removing pressure for reform that the machine-tool industry might otherwise have been moved to respond to.

The Soviets have not passively accepted their weaknesses in these fields; they have attempted on several occasions to duplicate what they have been importing, but without conspicuous success (at least as far as one can judge from the anecdotal evidence available). It is not clear from the pattern of failures whether they are due primarily to weak science and engineering (the "supply" side of innovation), or weaknesses in management, incentives, and organization (the "demand" and "transmission" sides), or some combination of both (for one can presume that each affects the other two). Whatever the exact mix of reasons (and there is no reason to assume it is the same in every industry or branch), Western technology alone is apparently not enough to overcome them. Indeed, the very availability of Western technology may delay Soviet efforts to grapple with the root problems of innovation by making it less urgent in the short run to do so. The price, of course, is a continuing lag behind the Western state of the art, and though influential Soviets may feel humiliated by such lags,[18] they may be thought of as the logical outcome of quite rational middle-term strategies on the part of the leadership, particularly in the handful of areas, such as agricultural chemicals, in which the productivity

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[17]The earliest and still the most striking illustration in the modern era is the transfer of modern industrial skills from Great Britain to the Continent in the late eighteenth and early nineteenth centuries. See David S. Landes, *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present*, Cambridge University Press, Cambridge, England, 1969.

[18]See Bruce Parrott's description in his forthcoming book, M.I.T. Press, 1981.

of imported Western technology is spectacularly higher than what Soviet enterprise would be able to achieve on its own.

4. *The more highly developed the Soviets' indigenous capabilities in a given branch of technology. the better able they are to profit from technology transfer (especially higher orders of transfer), and the less dependent they are likely to be.*

In some striking cases—such as heavy electrical equipment, welding, slag remelting, and heavy automotive equipment—the Soviets have demonstrated the ability to produce technology that, if not necessarily world-leading, is competent and capable of progress. It is internally generated, well adapted to Soviet needs and conditions, and increasingly competitive on world markets. In such areas the Soviets have demonstrated the ability to profit quickly and efficiently from Western technology, and the result is not dependence, but synergism, leading to an increase in Soviet technological strength in the fields concerned.

What accounts for this technological equivalent of the rich getting richer? This question actually contains two separate puzzles: First, what internal features of these industries account for their relative success? Second, what are the crucial skills or knowledge being transferred?

The traditional answer to the first question is high priority. But as we have seen earlier, there is considerable argument among Western specialists (and presumably among their Soviet colleagues too) about what high priority actually does. Clearly, one thing that high priority does is to assemble the best available elements that go into new technology: the best equipment, skilled manpower, and facilities. However, high priority on the supply side alone engenders ineffective protected industries, like the royal manufactures that mercantilist monarchies nurtured at great expense in the eighteenth century. The Soviet Union has done better than that by coupling higher priority with high pressure: deliberate stimulation of competition (e.g., among rival aircraft designers),[19] strong user demand (as in the case of military customers), or clear yardsticks of performance with rewards attached (such as cost per kilowatt-hour of generated electricity).

The example of the automotive, machine-tool, and electrical-equipment industries suggests a further principle: that political priority, in order to stimulate native innovative performance, must (in addition to the factors mentioned above) be sustained. Sudden increases in priority, on the contrary, appear to be counterproductive as far as indigenous technological innovation is concerned, especially if they are accompanied by a sudden flood of foreign technology. Thus, in plastics, synthetic fibers, agricultural chemicals, energy exploration (e.g., offshore technology) and gas transmission the impact of high priority has been too sudden for successful innovative performance in the context of a supply and training system that reacts slowly.

We turn now to the second question raised above: Where direct contact with foreign technology has had an obviously stimulative effect, what exactly are the useful elements being transferred? The case of the KamAZ foundry is instructive. By maintaining on permanent location at the Pullman Corporation a large rotating delegation of top engineers, the Soviet Union was gaining something that in the scale of possible transfers falls somewhere in the middle between the most concrete (such as finished products) and the most abstract (such as broad management philosophy): skills in the organization of design, assembly, maintenance, costing, and quality control. Such knowledge, half science and half art (the difference is crucial, because for science alone the Soviets are reasonably well equipped), is best transferred through practical example and informal contact, in other words by a process that amounts to apprenticeship. These are subtle skills, whose transfer apparently requires close working contact over an extended period. What is striking, however, is that they also require a certain minimum level

[19] See the memoirs of the noted military aircraft builder A. Iakovlev, *Tsel' zhizni: zapiski aviakonstruktora*, Politizdat, Moscow, 1970.

of skill, experience, and receptiveness on the part of the receiver. Technology, like contagious disease, requires a receptive host.

The conclusions we have outlined so far suggest that the interaction of various types of technology transfer with the Soviet environment produces three distinct zones, each featuring hypotheses with different implications for American policy:

A. *Transfer of finished products and processes as part of a Soviet crash program to improve an industry in which the Soviets start from a low level of capability.*

Hypothesis: In such cases the Soviet program of imports is poorly coordinated with internal improvements in the management of innovation, and yields no significant improvement in the Soviets' ability to generate and diffuse new technology on the basis of what they import.

Implication for policy: The consequence of such transfers is that they produce short-term gains in output capacity (such as synthetic fibers or plastics) rather than major improvements in innovative capabilities. From the standpoint of Western export-control policy, therefore, such transfers are of lesser concern, except insofar as they can be shown to overcome a major bottleneck in military-related production. Therefore the decision whether or not to grant an export license should depend primarily on whether the United States considers it expedient to contribute to the short-term production gains (such as increased oil production) for which the proposed export is intended.

B. *Transfer of skills and know-how in industries in which the Soviets have already shown considerable innovative proficiency.*

Hypothesis: The higher the native capacity of a given industry for innovation, the greater its ability to absorb and diffuse foreign technology as well.

Implications for policy: American policy in such cases should be to control transfers that involve "apprenticeship" relations (training, extensive joint work, etc.). However, any such policy must be tempered by a realization that the most that may be possible in such cases is a limited holding action, since the learning ability of the Soviets will be greater in such cases than in the backward industries, and in most instances they will have alternatives available from other countries.

C. *Transfer of general concepts about the management of incentive systems, information flow, division and coordination of tasks, etc.*

Transfer of "higher-order" skills of this kind may be important as a source of general examples. However, Soviet problems in the overall management of innovation arise not so much from the lack of foreign models—for there is every evidence that Soviet specialists are well acquainted with the models—but rather from long-standing, deeply rooted systemic obstacles to their implementation in the Soviet context. In addition, the Western literature on management and organization of innovation is so abundant and ubiquitous that it is hard to imagine any control mechanism by which its transfer could be prevented.

A CONCRETE ILLUSTRATION: THE CASE OF COMPUTER HARDWARE AND SOFTWARE

The Soviet computer industry in the late 1960s was a classic example of the effects of long neglect, compounded by faulty organization and management, limited user demand, and slow development of professional training. Since 1968, however, the Soviet computer field has enjoyed sustained political priority, which has taken the form not of a crash import program but rather an effort to build native skills while following Western example, largely as filtered through Eastern Europe. Whether this strategy is more the result of Western export restrictions or Soviet determination to build independent capabilities is difficult to say, but at any rate the Soviet computer industry is now reaching the same fateful stage in its development that its Western counterparts reached at the beginning of the 1970s: The chief limitation on further progress is not hardware but software. But in software the Soviet dependence on Western technology has been even greater than in hardware,[20] and their own innovative success has been smaller. Finally, the field of computers and computer applications is one of the few very clear cases in which Western management concepts have had a major impact on Soviet actions, resulting in efforts (however limited as yet) to change management structure in Western directions. What implications follow?

Export of much general-purpose computer hardware falls into Category A as described above, provided it can be modified (as in so-called "C" modifications to lessen the speed of Univac computers) to prevent military end-uses. This position is justified by the very rapid pace of technological advance in the West, which makes transferred hardware obsolete long before the Soviets have succeeded in copying it (the Ryad series, described on pp. 24-25, is a case in point), and paradoxically also by the high priority of computer development in the Soviets' eyes, which guarantees that any wide-spread type of computer hardware not transferred to the Soviet Union by way of commerce will cross the border by some other means.

Export of software falls into Category B, particularly that portion of it transferred by "live" apprenticeship.[21]

Finally, export of more general knowledge such as organization of service or computer applications in business falls into Category C. In some ultimate sense, this is the most important category of all. As Seymour Goodman ably argues, the concept of a technology as a package, including service, training, peripheral technologies and applications, is more vital in the computer field than perhaps any other. However, such "conceptual" matter relating to the management of technology and innovation is easily transferred (indeed, its transfer is impossible to stop) but not easily applied. It falls therefore in Category C.

BALANCING THE BENEFITS AND COSTS OF EXPORT CONTROLS

The issue of technology transfer to the Soviet bloc is a new instance of a very old problem: how to prevent the diffusion of valuable skills across national boundaries. History teaches that the control of technology transfer is at best a rear-guard action, achievable (and then only briefly) at the cost of regulations and secrecy that carry harmful side-effects of their own. This fact has not prevented every advanced nation from trying to impose controls at one time or another; in fact, since the beginnings of the industrial revolution, periods of relatively free exchange and transfer have been briefer than eras of control. But in the end the transfer of technology depends less on the fact that knowledge and skills have been divulged than on the

[20]S. E. Goodman, "Software in the Soviet Union: Progress and Problems," *Advances in Computers*, Vol. 18, Academic Press, 1979, pp. 231-287.

[21]See Charles L. Gold, Seymour E. Goodman, and Benjamin G. Walker, "Software: Recommendations for an Export Control Policy," *Communications of the ACM*, Vol. 23, No. 4, April 1980, pp. 199-207. Professor Goodman has been an active participant in the software subgroup of the Computers Technical Working Group (TWG.7), called to advise the undersecretary of Defense on the composition of the Militarily Critical Technologies List mandated by the Export Administration Act. The group has prepared an unofficial summary of its views, which the author is grateful to have had the opportunity to draw upon.

fact that the receiver knew how to make creative use of them. From the loss of the secrets of porcelain manufacture by the Chinese to the loss of the secrets of the Sidewinder by the Americans, the ultimate consequences depend on the ability of the receiver to profit from them—and on the ability of the donor to generate more.

It follows that balancing the political costs and benefits of export controls requires weighing their claimed effects in delaying the Russians against their costs in delaying us. An export-control policy based on the assumption that the enemy needs only to be exposed to superior American knowledge and skills in order to seize upon them, master them, and turn them into major gains prejudges the most important questions and may lead us into mistakes. The aim of this report has been to take a fresh look at the effects of technology transfers by calling attention to some of the important features of the Soviet context.

Naturally, this exercise is surrounded by uncertainties. To confirm or disprove the hypotheses advanced in this report, we would need to know a great deal more than we are ever likely to know, industry by industry, about Soviet strengths and weaknesses in generating and diffusing new technology. Neither do we know enough about how technological innovation works in general. We cannot predict in detail what kinds of transfers give Soviet technologists and managers the greatest help in improving their innovative performance—or for that matter our own. The translation of new ideas into new products and processes is still a mysterious business everywhere in the world, and no one explanation accounts for more than a fraction of the cases observed. This means, let us say it frankly, that it would be unwise to attempt to base any actual export-control policy on case-by-case evaluations of the Soviets' ability to absorb. The aim of this report is not to replace the critical-technologies approach with some sort of "critical-receivers" approach, for we simply do not have enough information or enough understanding to make it work.

Rather, the aim is to raise larger, cautionary questions about the broad course of export-control policy: Given the uncertainties surrounding any broadening of export controls, *in what direction is it safest to err*? The difficulties of technological innovation in the Soviet Union, and the largely negative results of recent reforms there, underscore some important points about innovation that are equally valid anywhere: First, however mysterious the details may be, it is clear that successful innovation depends on the presence of appropriate incentives and information. Potential inventors must know what opportunities exist and must stand to gain from good ideas, but also to lose from bad ones or from inaction. Potential users must know what has been invented and have both the motivation and the knowledge to choose correctly. If the Soviet system does not supply these incentives and information outside a narrow zone of closed high-priority projects, foreign imports will not fill the void.

Moreover, favorable climates for innovation, where they exist, are fragile. Regulation, however well-intentioned, introduces screens and filters between the perception of an opportunity for innovation and the inspiration and incentive to take advantage of it. Consequently, if the national purpose is to maintain the United States' technological lead, our first concern should be to remain good innovators ourselves. We should beware lest we hobble ourselves, as the Soviet system has so clearly succeeded in doing in the greater part of its industry.

What does this imply for export-control policy? The case for export controls is strongest in areas of immediate military relevance in which the United States has a clear lead over other Western countries. As one moves outside this zone, toward technologies that afford the Soviets longer-term industrial gains and that are not areas of clear American superiority over the rest of the West, the political benefits of export controls become more diffuse and uncertain, while the costs become progressively greater. Any widening of export controls outside the first range into the second should be undertaken only with the greatest care.

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SELLING THE RUSSIANS THE ROPE? SOVIET TECHNOLOGY POLICY AND U.S. EXPORT CONTROLS

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