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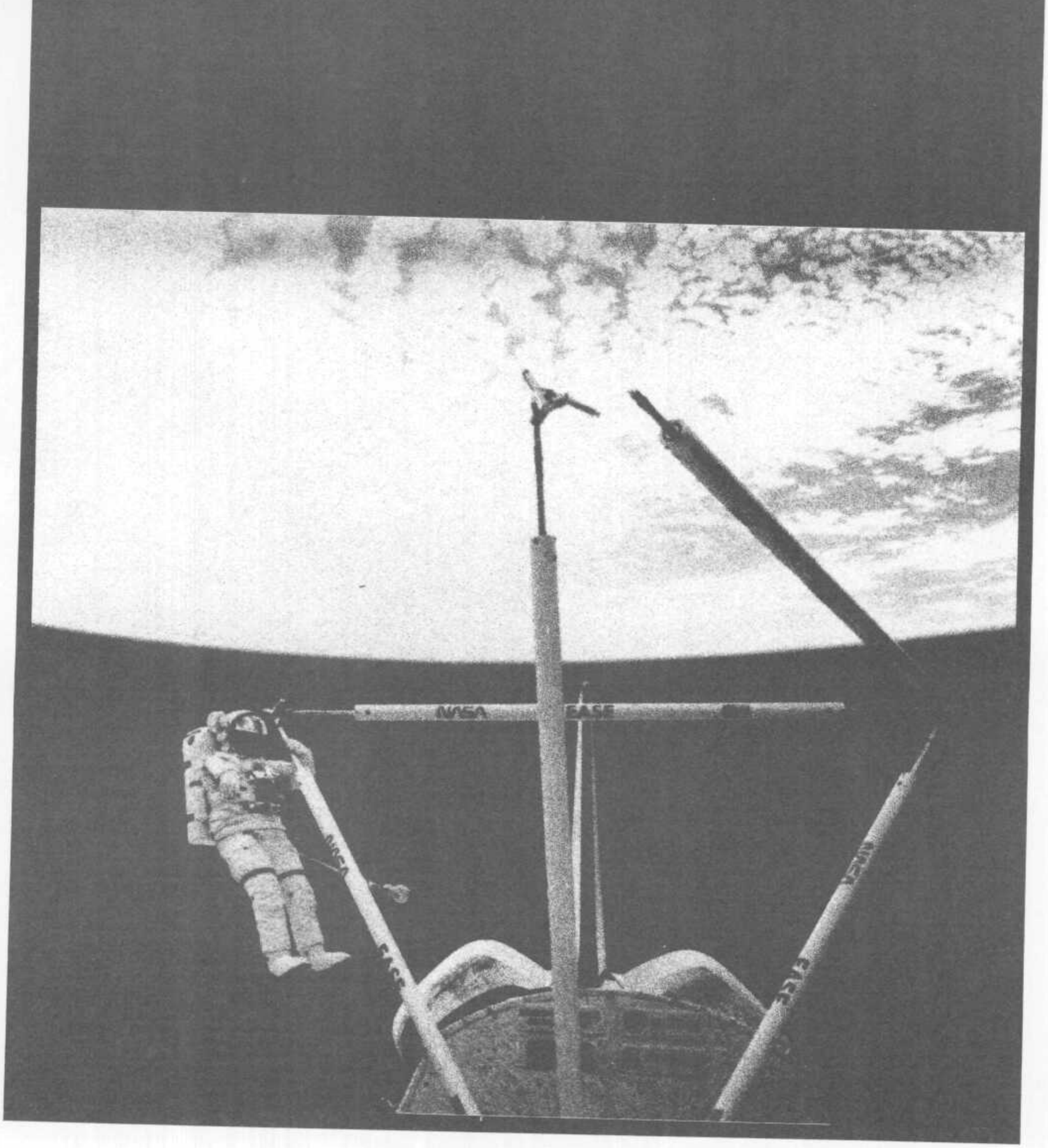
Encouraging Private Investment in Space Activities



A CBO STUDY

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S U M M A R Y

February 1991

CBO STUDY ON ENCOURAGING PRIVATE INVESTMENT IN SPACE ACTIVITIES

One of the aims of federal space policy has been to encourage private companies to invest in space activities. The CBO study, *Encouraging Private Investment in Space Activities*, finds that the prospects for developing private markets in the foreseeable future are too limited to provide any special justification for large investments in infrastructure, or even for the less expensive promotional programs. It does, however, find that increased private investment might help reduce the costs of the government's own space program.

In the market for services provided by large-capacity launch vehicles, federal encouragement of private investment has enabled U.S. producers of such vehicles to gain perhaps a third of the commercial launch market. Further steps in this direction by the government could include negotiating "rules of the road" governing international trade in the launch industry and investing in a new launch system to meet future government requirements. The latter option could enable U.S. producers to become more competitive in the commercial launch market.

Policy in another area--private investment in producing information by land remote sensing--is at a crossroads. Since 1984, the aim has been to transfer production of such information from the public sector to the private sector through the private company EOSAT. The study finds that the market is not likely to grow enough during the 1990s to support a fully private system. An additional $500 million to $1.3 billion in funding might be necessary during the 1990s to support a U.S. system, depending on the type of satellites built, the share of costs borne by the federal government, and the division of responsibilities between the public and private sectors. Private participation in the operation of a satellite system receiving federal support could enable more efficient operation and provide a continuing test of the market value of remote sensing.

In a third area, processing materials in space, the study finds that expectations of multibillion-dollar markets during the 1990s were overoptimistic. Still, public spending to exploit the future economic benefits of microgravity continues in the United States and abroad. Small experiments, designed and partially supported by private investors, have increased scientific and technical knowledge about the effects of low gravity on specific materials, among them protein crystals that have potential applications in designing new drugs. New programs expanding the availability of privately developed and operated orbital facilities might allow this success to be broadened, if they encouraged private interest in experimentation.

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ENCOURAGING PRIVATE INVESTMENT IN SPACE ACTIVITIES

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PREFACE

The goal of encouraging private investment in space activities has assumed an increasingly important position on the U.S. agenda in outer space. Significant federal expenditures have been applied to this effort, but additional spending will be required if the goal is to be achieved. This study by the Congressional Budget Office (CBO) examines the current status of private investment in space activities in three areas: the provision of space launch services by large-capacity launch vehicles; the production of information based on data gathered by satellites through remote sensing; and the processing of materials in space, along with the provision of necessary orbital facilities. The study was made at the request of the Senate Committee on Commerce, Science and Transportation, the House Committee on Science, Space and Technology, and the Senate Committee on the Budget. In keeping with CBO's mandate to provide nonpartisan analysis, no recommendations are made.

David Moore of the Congressional Budget Office's Natural Resources and Commerce Division prepared the study under the supervision of David Montgomery and Elliot Schwartz. Valuable suggestions were made by David Moser of CBO's National Security Division, Michael Sieverts of CBO's Budget Analysis Division, and Frederick Ribe of CBO's Fiscal Analysis Division. Many people in government, industry, and academia reviewed and contributed to various drafts of the study.

Francis Pierce edited the manuscript, Nancy H. Brooks provided editorial assistance, and Donna Wood typed the draft. Kathryn Quattrone prepared the study for publication, assisted by Martina Wojak.

Robert D. Reischauer
Director

February 1991

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SUMMARY

The federal government has adopted a broad policy of encouraging space commercialization, defined as increased private investment in activities related to outer space. This study examines that policy in three markets. Briefly described, the three markets are:

- o Providing space launch services by large unmanned rockets, also known as large-capacity expendable launch vehicles;

- o Producing information based on data gathered by satellites through land remote sensing--for example, photographs that convey information for use in agriculture, forestry, geological surveys, planning land use, mapping, and environmental monitoring; and

- o Developing science and technology related to the processing of materials under conditions of microgravity, including both the results of experiments and the orbital facilities necessary to conduct them.

Encouraging private investment in these markets would require direct federal spending. One argument for such spending is that public support would allow private investors to overcome existing obstacles and to create large new markets and industries in the near future. This argument is also invoked by those who want to expand the space program by building the space station or a new space launch system. It receives little support from the analysis of the three markets covered in this study. A second argument for federal support of private investment in space activity asserts that increased private investment would pay off by reducing the cost to the government of carrying out the public space program. The study finds limited evidence in all three markets to support this argument.

WHY COMMERCIALIZATION?

Space technology has developed to the point where private investors in space activity face a manageable technical risk. In this circumstance, the preference for private production and investment underlying the U.S. economic system implies that government should leave opportunities in space to the private sector. Those who believe that the government should play an activist role in commercializing space advance two arguments. The first is that the government can help to overcome obstacles in the private market that impede private investment. According to this rationale, space activities will ultimately create rapidly growing industries and markets. But private investors left to the guidance of the market alone will fail to invest enough to unlock this potential. The reasons are clear: they must accept a high degree of risk, make large investments, wait many years for a payoff, and face the possibility that competitors or firms in unrelated industries will share in these rewards. Federal intervention, by guaranteeing markets or subsidizing research or production, can make investment in space activity an acceptable alternative to other investments. For these subsidies to be justified, however, society's gain from investment in space activity must be large enough to cover the cost of the subsidy, as well as the profits investors could have received by choosing alternative projects.

A second rationale for the policy of space commercialization holds that to improve the efficiency of the public space program, private enterprise rather than the government should produce goods and services used in that space activity. Under this rationale, years of public production and control over space activities are seen as a barrier to private investors in space goods, who should at a minimum be assured a fair chance when competing with government production. Even if they increase the cost of the public program in the short term, policies giving positive support to new private investment may be justified if they create sufficient long-term savings to cover their initially higher cost.

THE CURRENT POLICY

The National Space Policy released by the Administration in November 1989 lists among its goals "encouraging United States private-sector investment in space and related activities." As a means to achieve this goal, it specifies that the government procure commercially available goods and services, and maintain restraint in competing with commercial suppliers of goods and services--within the limits of national security and public safety. The policy also endorses traditional forms of federal support for business, primarily transfer of publicly developed technology to the private sector and private access to public facilities on a reimbursable basis. Special note is made of the need for an active government role to "encourage free and fair trade [internationally] in commercial space activities." Significantly, the general statement of U.S. space policy is explicit in rejecting direct federal subsidies.

The policies and programs reviewed in this study's analysis correspond only roughly to the more general guidance of the overall statement of policy. In large-capacity launch vehicles, national security considerations have limited the commercial procurement of launch services. Specifically, in national security launches and some launches by the National Aeronautics and Space Administration (NASA), the government still purchases the vehicles and supervises the launch process. In the market for information gathered by remote-sensing satellites, the policy aims at a transition from a public system to a private system relying on private investment. Nonetheless, direct subsidies are currently being provided to a private U.S. operator of a system--Landsat--that the government paid for and developed. Private interest in processing materials in space is maintained by the government's promotion activities and by subsidies provided to investors willing to undertake experiments. These subsidies also benefit the providers of private orbital facilities necessary for the research. The government also offers more direct public support to these producers by purchasing orbital capacity from them, though it does this as much to encourage private investment as to meet federal requirements.

LARGE-CAPACITY LAUNCH VEHICLES

The U.S launch-vehicle industry now shows signs of delivering some of the benefits that have been used to justify the policy of space commercialization. For example, U.S. producers are now holding their own in direct competition with Arianespace, Europe's launch company, in launching satellites for communications service producers. This market is projected to range from $0.8 billion to $1.2 billion annually through 1994. As these commercial practices are carried over to the U.S. government or "captive" launch market, the U.S. public sector stands to benefit through lower-cost launch services. After the mid-1990s, however, conditions are likely to change as new foreign suppliers enter the industry and offer lower prices to a smaller commercial market. Maintaining the U.S. share in the commercial market, and the benefits of commercialization in the government market, could require a public investment in new launch systems to reduce costs, along with a trade policy that would discourage foreign launch services from offering markedly low prices.

Current Outlook

The Delta, Atlas, and Titan vehicles, produced by McDonnell Douglas, General Dynamics, and Martin Marietta respectively, have won contracts for a third of the commercial launches scheduled into the mid-1990s. Arianespace holds more than half of the market. Beyond that time, however, the prospects for U.S. producers and the market as a whole are not bright. The demand for launches in the commercial market is projected to average between 15 and 20 satellites annually through 1994, but only 12 to 17 satellites a year thereafter through 2000. However, governmental investment in space launch capacity will increase the supply of launch services after 1995. Excess supply and aggressive competition will characterize the market at that time. U.S. producers may be unable to compete without the continued support of the federal government.

Governments determine the supply of large-capacity launch vehicles. Commercial launch services can be brought to the market only because the public sector requires launch vehicles for its own purposes. Initially, these purposes included only space transportation for military and civil government satellites and, to a lesser extent, for enhancing national prestige. A boost in motivation came after the Ariane family of vehicles was developed by Europe and the manned space shuttle by the United States. Each of these programs sought to supply launch services to the commercial market and thereby achieve economies of scale and lower the cost of launching public payloads. In the United States, after the shuttle system failed to live up to expectations, the commercialization policy was applied to expendable launch vehicles.

China, Japan, and the Soviet Union, newcomers to the commercial market, share some mixture of these same motivations. All have invested in increasing space launch capacity for public purposes: national security, national prestige, or in the belief that a technically advanced country must have its own national flag carrier in space. All have, or will soon have, capacity in excess of national requirements, and this capacity can be offered to the commercial market. The cost of the excess capacity will depend on the volume of vehicle production and on the scale of the launch system, both of which are essentially determined by public policy decisions. Obviously, large-volume producers can bring services to the market at a lower average cost than smaller-volume producers. However, while U.S. and European producers currently have this advantage, it could fall to the Soviet Union if the Soviets overcome the political obstacles to entering the commercial market.

Policy Options

The rise of a commercial market for launch vehicles presents the United States with the option of adopting a freer trade policy in launch vehicles. Such a policy would permit Soviet, Chinese, or other groups to launch commercial communications satellites manufactured in the United States, without attempting to force the price charged by these offerers to be at a "par" with that offered by Arianespace or the three U.S. producers. A more open trade policy would also include opening parts of the U.S. government market to foreign suppliers.

The benefits of freer trade would be lower launch prices for satellite owners and ultimately for the consumers of satellite services. For the United States, indirect benefits could include leverage in opening foreign markets to U.S. satellite manufacturers, and the marginal contribution of higher export earnings to political stability in the Soviet Union. Without dramatic reductions in the cost of U.S. launch vehicles, however, freer trade would be likely to force one or more of the three U.S. firms out of the commercial market. Moreover, an indirect cost of freer trade could be a diminished capability to support national security launching needs in the event of an emergency.

An alternative to freer trade would be to negotiate rules of the road with Europe and with new entrants to the market that would force all parties to offer prices on a "par" with those offered by European and U.S. producers. Such a system would give U.S. private investors a better prospect of maintaining their position in the commercial market than would freer trade, but it would by no means guarantee their future success. In the mid-1990s Arianespace, with the support of the European Space Agency, plans to offer a new, lower-cost vehicle, the Ariane 5, that could substantially lower Arianespace's costs within a rules-of-the-road framework. U.S. producers cannot expect to achieve competitive reductions in cost, since no comparable U.S. public program is under way, and the commercial market is too small to justify private investment in new cost-reducing launch systems. However, if a negotiated trade policy allowed U.S. producers to maintain their current production rates, more capacity would be available for the government market in the event of a national emergency.

A negotiated trade approach would also mean higher prices for private satellite launches. In addition, to the extent that a freer trade option could enable the U.S. government to reduce the cost of some of its space launches by taking advantage of lower-priced foreign offers, these benefits would also be forgone. Finally, a negotiated trade policy in launch vehicles would be unlikely to grant additional leverage to the United States in opening related aerospace markets.

Whatever the decision as to trade policy in launch vehicles, the government could undertake to support the development of technology and new launch systems that would lower the cost of commercial space launches. For example, advocates of a propulsion technology program requiring a $5 billion dollar investment believe that it would reduce costs by 50 percent. The President's budget for 1992 includes $350 million, split evenly between NASA and the Department of Defense, for developing a "new launch system" that would offer even greater cost reductions for an investment of between $10 billion and $15 billion. The commercial market in itself is not large enough to justify such outlays; in conjunction with a significant increase in public launch activity, however, spending at these levels might be warranted. In that case, a secondary benefit of the higher spending would be an increase in the commercial sales of U.S. expendable launch vehicles.

A dramatic reduction in the cost of launch services would probably result in the emergence of a single private U.S. launch provider, since the government would have to concentrate its purchases of launch services in order to realize the full benefits of the cost-reducing technology in which it had invested. In that event, the monopoly power the single private supplier would have in the government market could partly offset the benefits of lower-cost launch services and a larger U.S. share of the commercial market. That monopoly power could be limited, however, by opening parts of the government market to foreign suppliers.

The policy of commercializing launch services has sought to lower the cost of government launches by substituting commercial terms and procedures for the government's traditional way of purchasing vehicles and directly supervising launches. This approach could be extended to parts of the government market currently served in the traditional way. One option would be to allow public satellite programs to purchase launch services on the open market. The savings from pursuing this option could be limited, however, since the most expensive national security satellites are to be launched by the Air Force on the Titan 4 vehicle, for which no commercial substitutes are available.

DATA GATHERED BY SATELLITES THROUGH LAND REMOTE SENSING

Satellites gather a wide variety of data that can be used to produce information valuable in mineral and petroleum exploration, agricultural assessment, civil engineering, managing land use, forestry, and map making. In 1972 NASA launched the first civilian land remote sensing satellite, as a research and development project. Four satellites later, at the end of 1984, the cumulative public investment in civilian land remote sensing systems stood at $1.5 billion.

In 1984, the Congress decided to commercialize the Landsat system, as the two satellites currently in orbit and their supporting ground stations are known. The government selected the Earth Observation Satellite Company (EOSAT), a joint venture of Hughes Aircraft and General Electric, to become the private producer of remote sensing data. Currently, EOSAT receives annual subsidies to operate Landsat 4 and 5, and has received public funding to cover most of the cost of building and launching a new satellite, Landsat 6, in the first half of 1992.

Current Outlook

EOSAT and the policy that created it are in flux. EOSAT operates as a private firm and by most accounts has introduced cost-cutting measures and improved the quality of its products since it took over from the National Oceanic and Atmospheric Administration, the last federal operator of the system. Its revenues have grown from around $17 million in 1985 to $25 million dollars in 1989. A consensus of recent studies holds, however, that additional federal spending will be necessary during the 1990s to build new satellites. Satellite remote sensing does not appear to be a potentially dynamic growth industry that could be said to need government support to overcome market barriers. Even government efforts to encourage private investment in the field must face the question whether the data obtained from land remote sensing are worth their cost to society.

The revenues from the sales of data produced by land remote sensing systems of the Landsat type--including Landsat and the European SPOT system--cannot cover the cost of the data produced. To justify continued public support, one would have to show that the value of the data to society is greater than the value observed in the market. That may be true for several reasons, although this study provides no definitive evidence.

First, satellite remote sensing data are easily reproduced. The customers purchasing the data from EOSAT can at little cost distribute the product to other public or private users for whom it may have a value not reflected in the price paid to EOSAT. Second, the legal restraints on EOSAT's pricing and distribution policy may shift too much of the ultimate value of its product to its public and private customers. A third and related reason is that Landsat data are used in producing public goods that are difficult to value, and Landsat's public-sector customers may not be paying as much for the data as they are worth. The willingness of other governments to support land remote sensing satellites suggests that the social value of land remote sensing systems may be worth their cost. The U.S. government's own commitment during the 1990s to research on global change, and to spending $17 billion on the Earth Observation System--a set of remote sensing satellites--provides similar supporting evidence.

Policy Options

The options open to the federal government to encourage private investment in land remote sensing depend first on a decision about the ultimate value of Landsat. If Landsat's value is not enough to justify its cost, no further federal expenditures should be made. Without federal spending for new satellites in the mid-1990s, Landsat will probably fail. In that event, the Congress could choose to encourage new private investment in remote sensing satellite systems by deregulating the market for remote sensing data. New private investors could be permitted to charge different prices to different customers and to grant exclusive data rights to customers willing to pay for them. If private investors were to enter the market under these circumstances, they would probably do so with satellite systems that are smaller, less expensive, and less capable then Landsat. But the prospects of such "lightsats" are not encouraging, according to several studies conducted in 1988, although their worth has yet to be tested in the market.

If the Congress decides that the social value of land remote sensing justifies providing support for satellites during the middle and late 1990s, several different institutional options are open to it. The government could continue the current arrangement of subsidizing a private operator, but this could include a substantial private contribution to the cost of satellites built during the 1990s. The level of the contribution could be determined in an open competition or by direct negotiation between EOSAT and the government. Alternatively, the government could reassume full responsibility for land remote sensing, assigning a single federal agency or group of agencies the tasks of designing and operating satellites and distributing data. A third option would be to form an international consortium with Europe, Japan, Canada, the Soviet Union, and other countries to share the cost of new satellites in the future. A private operator could be included in this option. The costs of these options through the year 2000 could vary from $500 million to $1.3 billion, depending on the type of satellites built, the share of their cost that the federal government covered, and the role the government assumed in operating the system.

The most expensive option would probably be a national system operated by the federal government, since neither a private partner nor a foreign government would share in the costs of satellites. Moreover, the satellites themselves would probably be designed to serve not only current uses but new research applications as well, and thus would cost more to build, although the costs would be partially offset by revenues from data sales flowing to the government. A strength of this option, however, would be its ability to set data prices low, making data more widely available. Both continued research and low data prices are consistent with the view that the social benefits of land remote sensing far exceed its costs and should be aggressively sought.

An important institutional drawback of this option has been the historical inability of the Landsat system to find a supportive federal agency that views the production of data as a vital part of its mission. Agencies that could play a leading role in a public system include

NASA, the Department of Defense, the Department of the Interior, and the Department of Commerce.

If Landsat-scale satellites are to be supported during the 1990s, the least costly option open to the federal government may be to retain a private operator for the national system. Under this option, if the government shared the cost of new satellites with EOSAT or another private firm, it could encourage private investment in the production of land remote sensing data. The rationale for this policy would be the superiority of the private sector in determining what satellites should be produced, and in operating the system once in orbit. The price charged for data by a private operator would presumably be higher than that charged by a public operator, and indeed the level of prices a private operator charged would increase with the amount it contributed to the costs of new satellites. Yet, this price level could still be below that of the other options--if, for example, a fully public system included very expensive satellites, was operated inefficiently, or came under pressure to recover a part of the capital costs of the system in the prices it charged consumers of data. Also, retaining EOSAT as a private partner would offer the advantage of providing continuity to a program that has been beset by political uncertainty throughout its existence. Moving in this direction without competition, however, would not permit a test of the willingness of other potential investors to share the cost of satellite systems.

The third option would be to create an international consortium with either a private or a public U.S. representative. An international arrangement, sharing a single system, would certainly cost less in total than the various national systems in operation today and those planned for the mid-1990s. The economics of the industry are such that data are produced under conditions of declining average cost and weak market demand, so that producers cannot cover all their costs in a competitive market. A single world producer could overcome this limitation by pricing its data differently when selling to different customers. While current U.S. law does not allow such price discrimination, the rationale for this restriction would be undercut by an international organization that guaranteed access to data for all nations and users.

From the U.S. perspective, however, a consortium would have drawbacks. Cost saving could be substantially reduced if satellite procurement was based on political as well as technical factors. U.S. private firms could be forced to pay higher prices for data under many pricing formulas that involve discrimination among types of buyers. Finally, a single government-sponsored international monopoly could forestall the evolution of the current market toward one in which private investment could stand on its own.

MATERIALS PROCESSING IN SPACE

In the early 1980s expectations were high that the pharmaceuticals, electronics, and chemicals industries could profitably exploit the low-gravity, or microgravity, conditions available in outer space. The increasingly capable public space program--initially employing the shuttle and later the space station--was to be the springboard for new products and processes that would create billion-dollar markets as early as the 1980s. While experience since then has deflated the vision of large new markets in the near term, more modest hopes continue to support both public and private activities. The United States, the Soviet Union, Europe, and Japan are all involved in processing materials in space--in activities that extend beyond pure science to commercial and industrial applications. The goal of processing materials in space is cited by all of them as a justification for past and future investments in manned space stations, including the Soviet MIR and the U.S.-sponsored international space station.

Current Outlook

The ultimate commercial viability of processing materials under microgravity conditions in space is yet to be demonstrated. Nevertheless, substantial public resources in the United States and abroad are being directed toward understanding the behavior of materials under low-gravity conditions. This country budgeted about $100 million in 1991 on the materials-processing science program alone, not to mention additional spending in other accounts on transportation, facilities, and commercial promotion roughly doubling that amount. Spending in all of these areas is planned to grow, with the science program projected at an annual level of $285 million by 1996. While the space station has many purposes, a part of the $20 billion to $30 billion it will require during the 1990s must be seen as support for processing materials in space, a point emphatically made by the Congress in appropriating funds for NASA's 1991 program. The U.S program is as well supported financially as any of the other national efforts. This support extends to private investors, including suppliers of orbital facilities and industries that are potential users of the materials.

Private investment in the materials-processing experiments is extremely small, both in relation to public spending and to the amounts spent by the would-be industrial beneficiaries in other research areas. The U.S. and foreign programs have sought to increase private spending and general interest by providing a framework for cooperative research and subsidies to lower the cost of experiments. The U.S. effort, under the title of Centers for the Commercial Development of Space, compares well with foreign programs.

Policy Options

The current emphasis in processing materials in space is on experimenting and applying experimental results to Earthbound products and processes. Public spending in science, technology, facilities, and experimental activity accounts for most of the resources applied to processing materials in space. The primary emphasis of the U.S., European, and Japanese public efforts is on using the space shuttle and its Spacelab payload as an interim laboratory to generate scientific results and develop technology that will build the potential for productive use of the space station sometime in the late 1990s. Delays in the space shuttle flight schedule and the development of the space station program have slowed progress in this primary effort. Government-supported experiments with commercial participation, while also suffering from delays in the shuttle, have provided an alternative path to progress in science and technology, producing experimental results through small-scale, low-cost experiments. The small scale of these experiments has permitted them to fly the shuttle as "secondary payloads" and to gain access to space on small rockets unaffected by shuttle delays.

Recent initiatives by NASA have tried to expand private participation in materials processing in space from users of experimental facilities to providers of these facilities. Because the NASA primary science program has been held back by the slowdown in shuttle flights and is also constrained by the delay in developing the space station, the most obvious alternative is to expand small-scale facilities. Two moves in this direction are the Commercial Middeck Augmentation Module--a set of lockers that expands the shuttle crew area and permits more experiments to be flown on a shuttle mission--and a returnable capsule system that would be placed in orbit by a small rocket and carry small experiments, the Commercial Experimental Transport System. Whether or not introducing new private orbital facilities can continue the limited success evident in the current effort is an open question, in that the current success of commercial activities stems as much from their small scale as from their private character.

Using private orbital facilities might or might not cost the government less than the traditional system of public procurement. It would cost less if the facilities also provided services to the private sector or to other governments. Traditional procurement would cost less, however, if the government was the sole user of the facilities, because the private sector's capital costs are higher. For example, an evaluation by the National Academy of Public Administration of a proposal that NASA lease a small space station called the Industrial Space Facility, or the Commercially Developed Space Facility, showed that the cost of private financing, ownership, and operation were so much greater than traditional procurement that the government was better off purchasing the facility outright than leasing only 70 percent of its services.

Another instance in which private facilities might cost less would be one in which the traditional procurement process ends up increasing the basic cost of the facilities because of bad management or a governmental proclivity to overdesign or to permit too many design changes. If, however, the government's goal was limited to aiding access to microgravity for U.S. public and private experimenters, a less expensive option than either promotion of U.S. private facilities or traditional public procurement would probably be to purchase services provided by foreign facilities, most prominently the Soviet space station MIR.

The government's dominant position as a customer for orbital facilities implies that in most cases, when traditional procurement can be efficiently undertaken, the service purchase option will be more expensive. One can make the argument, however, that the higher cost of purchasing private services will ultimately be justified if they prove to be more productive in attracting new private users to microgravity experimentation. This proposition has not yet been tested, but it will be if NASA's program to promote private orbital facilities goes forward as planned.

CHAPTER I

INTRODUCTION

Should private investment play a larger part in the national space program? Some people see increased opportunities for private enterprise in producing goods and services related to space, and hold that one purpose of the space shuttle and the international space station should be to foster such private activity. They also contend that commercializing space activities will enable the government to pursue the traditional objectives of the national space program--science, exploration, and national security--at less cost, because private investment will make available a broader array of less expensive goods and services. While direct federal expenditures to promote private investment in space activity are small relative to total federal spending on space, a large part of the government's nonmilitary spending on space is partially justified as contributing to the commercialization of space.

This study analyzes the status of private investment and its relation to federal policies and programs in the markets for:

- Space launch services provided by large unmanned rockets, or large-capacity expendable launch vehicles;
- Land remote sensing data gathered by satellites--for example, photographs that are used to produce information for agriculture and forestry assessment and forecasting, geological surveys, planning land use, mapping, and environmental monitoring; and
- Science and technology related to the processing of materials under conditions of microgravity in space, including both the results of experiments and the orbital facilities necessary to conduct them.

The three markets considered do not include all potential commercial activities related to space. The study does not include satellite communications services, which have become the most successful private business relating to space, nor does it consider several new prospects such as satellite navigation and positioning services. The focus on three markets does, however, allow examination of most of the general issues related to federal policy encouraging the commercial use of space.

The terms "commercial space," "commercialization of space," and "space commercialization" are defined in this study as private investment in space activities. They do not include traditional contracting between government agencies and established aerospace companies, nor the technologies randomly spun off from the public space program to private industries. Commercial space activities focus ultimately on private markets beyond the government or, at a minimum, involve significant private capital at risk. The products and services brought to the market by commercial space producers are designed, developed, or produced by the private sector itself, rather than by the private sector under the oversight of government managers.

BACKGROUND

The National Aeronautics and Space Act of 1958, as amended, directs the National Aeronautics and Space Administration (NASA) to "seek and encourage to the maximum extent possible the fullest commercial use of space." The National Space Policy, released in November 1989, is the current Executive Branch statement on how this objective is to be achieved, not only by NASA but by all federal agencies.[1] Expressions of support for private investment in space activities date back to the early 1980s.[2] While the desire for increased private investment in space activity has remained a constant of national policy, the basis for federal concern and spending in supporting new private investment has broadened over time.

1. White House press release, "U.S. National Space Policy" (November 16, 1989).

2. John M. Logsdon, "Space Commercialization: How Soon the Payoff?" *Futures* (February 1984), p. 71.

The actions the federal government has taken to promote private investment in space activity include direct promotional spending, spending on multipurpose infrastructure, reexamination of federal procurement practices, and active trade policy to promote free and fair trade in space markets. In some respects these do not differ from federal policy toward other markets. In other respects, important differences are evident. The size of the expenditures on infrastructure--most prominently on space shuttles and space stations--and the frequency with which commercial gain is noted as a reason to go forward, invite scrutiny. The offer of direct subsidies to individual investors or firms in the cause of space commercialization is also unusual. By and large, these and other exceptions to the usual relation between government and industry have been justified on two grounds. First, active support of private investment in space is necessary to create new markets that otherwise would not grow, or, worse yet, would be dominated by foreign firms. Second, introducing new private producers into the market for space activities should permit the government to lower the cost and improve the quality of the public space program.

Creating New Industries

Space has been portrayed as a new economic frontier calling for major public investment in the new industries created by opening this frontier. NASA's development of the space shuttle transportation system required an investment of $27 billion (in 1990 dollars) through 1984. These expenditures were justified on a variety of grounds ranging from national security and prestige, to scientific and engineering advancement, to the opening of markets for private investors. The shuttle system was expected to fly about 50 times a year, and to be available to paying customers at a fraction of the cost of unmanned rockets. Other inducements--the cooperative funding of private research by the federal government, and free or reduced prices on shuttle flights for new commercial ventures--were also seen as necessary to bring new private investors into the risky and foreign environment of space.

Despite the shuttle system's failure to deliver low-cost, frequent access to space, and the general failure of large new private markets to develop, the essentials of the new-industry case continue to be put forward as a justification for current and proposed spending on space. In 1991, $4.2 billion was appropriated for the shuttle system. Part of this was to provide an orbiting laboratory to explore the commercial potential of microgravity materials processing. NASA's Commercial Use of Space program has requested $118 million in 1992 to promote the commercial use of space. Arguments similar to those justifying the initial investment in the shuttle are now being put forward for the space station, a program estimated to require direct spending of $20 billion to $30 billion during the 1990s. Proposals for additional spending for launch vehicle technology and remote sensing satellites continue to be made, in part to support U.S. private interests in the space markets of the future.

The basic economics of the "create new industries" case for federal support of current private investment in space activities is that the normal functioning of the private market would lead society to underinvest in space activity. The rationale for this is that space investments involve extraordinary risk and costs, and require long periods of time between investments and returns. Moreover, a private investor in space activity may not capture all the potential returns; instead, some of the returns may be realized by competitors, suppliers, or investors in other markets. For example, techniques developed to manufacture materials in space may benefit all potential private investors, not only those that bear the cost of development. While the use of such techniques may increase society's well-being and income, individual private investors will only invest in projects to the extent that they benefit directly. By subsidizing facilities and research, the government can encourage more activity and correct the market's failure to invest enough in space.

Closely associated with the argument for direct federal support to create new industries is the claim that foreign businesses are receiving government support for investments in space activities and that as a consequence the future competitiveness of the U.S. economy will be hurt if the United States does not provide similar support. The popularity of the argument that public investment will ultimately lead to large new opportunities for private investors is partly explained by concern about the U.S. trade deficit, both now and in the future.

The argument for competitiveness needs careful scrutiny. A "competitive" economy is one that can produce and sell goods and services internationally while maintaining a rising standard of living domestically. Government intervention that leads to more productive uses of domestic resources--as would occur if the thesis of expanding space markets is true--will invariably result in a more competitive economy. Improving overall productivity means that fewer domestic resources will be necessary to generate the income necessary to purchase imports, and that goods and services produced in the United States can be offered on the international market at a lower price. But export sales that are only made possible by permanent subsidies will reduce overall productivity. Such sales may contribute to the trade balance, but they will lower the domestic standard of living. The beneficiary of export subsidies is ultimately the foreign consumer, who pays less for the subsidized goods or services.

Increasing the Efficiency of the Public Space Program

A second general argument for the policy of federal support for new private investment in space is that private enterprise can produce the public goods required in space activity at less cost and improve their quality. Public goods are those goods or services that, like national defense or prestige, can be consumed by any one consumer without diminishing the amount available to all other consumers. Most of the space activity undertaken around the world--exploration, pure science, and environmental monitoring--fits the definition of a public good. That is, an individual can consume space activity without diminishing the amount of it available for other individuals. While government ultimately funds the production of public goods, either private producers or government enterprises can undertake their actual physical production.

The argument for bringing private-sector efficiency to the public space program has gained strength from the difficulties with performance and cost that have beset the military and civilian space programs. The National Space Policy emphasizes the use of commercially available goods and services as a means of increasing private investment in space activity. For example, government agencies have been directed to purchase commercial launch services, rather than buy the vehicles themselves. The Augustine Report also suggests that a larger reliance on commercial procurement would improve the performance of the government space program.[3]

This argument that private investment will increase the efficiency of the space program relies on the superiority of market incentives in controlling cost and quality. Large parts of the space effort operate as public enterprises--including the space shuttle, the weather satellites, and a variety of defense activities. Advocates of federal support for private investment emphasize the tendency of federal agencies to hold onto production activities well beyond the time when private production is a possibility. Accordingly, they point to the need to grant those who offer private services the benefit of a doubt when confronted with the choice between public production and the purchase of private services. The issue here is not encouraging a future private market but reducing the cost at which public goods are to be provided, regardless of whether or not the government remains the dominant customer.

EVALUATING INVESTMENT PROSPECTS AND POLICY OPTIONS

The three chapters that follow evaluate the two larger rationales for federal support of private investment against the prospects for such investment in each of the three markets included in the study. Each chapter begins by reviewing the recent history of public policy and private investment in the market covered, describes supply and demand conditions affecting private investment in that market, and closes with a discussion of policy and spending options.

The three markets share one important characteristic: more than most U.S. industries, they are subject to governmental policies. The federal government plays a unique role in its pursuit of national security, space exploration, scientific knowledge, and other public benefits of space activity. The government is also involved in providing ser-

3. National Aeronautics and Space Administration, *Report of the Advisory Committee on the Future of the U.S. Space Program* (December 1990), p. 43.

vices and facilities, as well as in the international aspects of most space activity.

Despite this unique federal role in private space activity, one can analyze the industry in much the same way as any other industry. Successful private investment in space will require that existing goods and services be improved or produced at a lower cost, or that new goods and services be created, and that their production be supported by market demand. The demand for goods and services that require space activity will translate into a demand for launch vehicles, spacecraft, and ancillary services. The factors shaping these outcomes can be divided into the supply and demand conditions for each technology and market. The effects of government policy as a promoter of, or obstacle to, commercial space activities can be assessed in this context.

Several recent studies of federal policy toward private investment and commercial activity in space have assumed that substantial growth in the sector is inevitable. This study does not share that assumption. A successful and growing role for commercialization is only one possible outcome. For example, the private sector may continue to be limited to traditional contractor and spin-off relations. Or commercialization may be more successful in some markets than others. A significant implication of assuming that growth is not inevitable is that commitments by other governments to commercialize or privatize space activities may not succeed. If the question is open for the U.S. industry, it is equally open for investments made by foreign governments and firms.

CHAPTER II

LARGE-CAPACITY LAUNCH VEHICLES

The decision made in 1983 to commercialize the services provided by expendable launch vehicles marked a departure from government monopoly of space transportation. It remains an open question whether commercialization will lead in a fundamentally new direction, or become a mere detour on a road heading back to government domination of space transportation. The policies the federal government adopts in trade, technology development, and procurement will be critical to the future of a viable commercial launch sector. Also critical, however, will be the actions of U.S. firms and foreign governments, and the rate at which the market demand for launch services grows.

LAUNCH SERVICES: THE CURRENT OUTLOOK AND POLICY OPTIONS

Since the Challenger accident in 1986, the three U.S. producers of large-capacity launch vehicles--McDonnell Douglas, General Dynamics, and Martin Marietta--have created a significant U.S. presence in the world market. The U.S. producers had virtually retired their vehicles by 1986 after the federal government decided earlier in the decade to rely on the space shuttle for all public-sector requirements. A renewed federal commitment to use the large-capacity Delta, Atlas, and Titan for government launches after the Challenger accident was a necessary first step in allowing U.S. firms to reenter the commercial market (see Box 1).

Nevertheless, Europe's Arianespace will retain over half of the $0.8 billion to $ 1.2 billion annual commercial launch market through 1994. The three U.S. producers and China's Great Wall Industries will share the rest of the market. The Atlas vehicle of General Dynamics and the Delta of McDonnell Douglas have been more successful than Martin Marietta's Titan.

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BOX 1
Commercializing Large-Capacity Launch Vehicles

In the past, governments have developed and operated launch vehicles and launch services. The United States and the Soviet Union developed their families of launch vehicles to meet a combination of national security and civil scientific needs. Until the 1980s, the United States government was the sole provider of launch services to the non-Communist world. U.S. aerospace firms acted as contractors to the government in developing launch systems, producing launch vehicles, integrating payloads with launch vehicles, and assisting in launch operations. Commercial clients, consisting entirely of communications satellite operators and foreign governments, reimbursed the U.S. government for a portion of launch costs.

When the era of the space shuttle began with the flight of the orbiter Columbia in 1981, some observers predicted explosive growth in the demand for space launches. Against this background, the U.S. government decided to depend on the reusable, but manned, space shuttle system for all of the public sector's space launch needs. The policy implicitly saw the use of disposable rockets, or expendable launch vehicles (ELVs), to carry both cargo and people into space as obsolete technology. The shuttle would conduct all public-sector space launches and be the United States' international champion in the commercial launch market. This market would be open to private ELVs, but ELVs--whether U.S. or European--were seen as becoming uncompetitive by the majority of the U.S. policy community. By virtue of the shuttle's projected flight rate of 40 to 60 flights annually, its services would cost as little as one-fifth of those of a comparable ELV.[1]

When the shuttle system's performance fell far short of expectations, issues of competition came to the fore--between the shuttle and ELVs, and between the U.S. and European launch systems. The price charged by the U.S. government to launch satellites on the space shuttle became a competitive battleground.[2]

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1. Congressional Budget Office, *Pricing Options for the Space Shuttle* (March 1985), p. 4.

2. *Pricing Options for the Space Shuttle*, pp. 37-39.

A U.S. ELV provider, Transpace Carriers, brought a trade complaint against Europe's Arianespace, contending that the latter received unfair support from European governments. The trade complaint was disposed of as an instance of offsetting subsidies. The U.S. Special Trade Representative found that European support for Ariane was consistent with the history of the launch services industry, and no greater than the support of the U.S. government for its own provider, the space shuttle.[3]

The Challenger accident of 1986 resolved the specific issue of competition between the public shuttle and private ELVs. In the wake of that disaster, the government established policies to ensure the survival of U.S. ELV producers through the 1990s. Commercial payloads that did not require its unique capability were barred from the shuttle. Executive Order 12465 designated the Department of Transportation as the lead federal agency for commercial ELV activities. The Commercial Space Launch Act of 1984 established the jurisdiction of the Department of Transportation through its Office of Commercial Space Transportation in regulating and promoting the commercial launch industry. In playing this role, the office has assisted in solving a number of start-up problems between the government and private launch companies. These include safety standards, range fees, use conditions, and insurance regulations. National Security Decision Directive 254, issued in late 1986, removed the government as a competitor in the communications satellite launch market and specified that the government buy launch services rather than launch vehicles to meet many of its launch needs. Consequently, rocket production lines were kept alive, and with them the possibility of a U.S. competitive presence in the world commercial launch market.

3. Glen H. Reynolds and Robert P. Merges, *Outer Space: Problems of Law and Policy* (Boulder: Westview Press, 1989), pp. 231-237.

The policy of commercialization has more than one objective. In addition to contributing to exports, it aims to lower the cost of public-sector space transportation. Because the cost of producing launch vehicles falls as more are produced, domestic policies that encourage competition in the government's captive market and winning contracts in the commercial market provide complementary incentives for U.S. producers of launch vehicles to lower their costs. This policy of commercialization has placed the Delta rocket of McDonnell Douglas and the Atlas rocket of General Dynamics in direct competition for U.S. government launches. The additional prospect of winning launches in the international commercial market intensifies the pressure to lower cost, not only to meet competition in that market but also because even a small number of sales of additional vehicles enables lower-cost production for the larger U.S. captive market.

The outlook for the second half of the 1990s is not as bright. Weighing against continued success in the commercial market is the overall decline in demand for launch services provided by large-capacity vehicles, the likelihood of improvements in Arianespace's cost and performance, and the entry of new foreign competitors--most important, the Soviet Union. U.S. producers will continue to manufacture their vehicles as long as the federal government continues to buy them, but will be hard pressed to maintain their market share of the commercial market. Consequently, one can expect lower exports of launch vehicles and slightly higher costs for U. S. public-sector launches.

The federal government could take several steps to promote the interests of private investors in large-capacity launch vehicles, and in doing so, extend the success of the current policy into the latter half of the 1990s. The costs would increase, however, both in terms of direct federal expenditures and in the higher prices the commercial consumers of launch services would pay. In the trade arena, the United States could negotiate with Europe a set of rules for launch-service pricing, which would slow the entry of very-low-priced Chinese and Soviet launch vehicles into the world market. Current U.S. investors in launch services would gain in their market share, but all buyers of launch services--U.S. investors in satellite services among them--would pay higher prices. While the alternative, a freer trade policy, would probably mean lower launch prices for consumers, and could even be extended to the U.S. government market by permitting foreign competition for payloads not involving national security, such a policy would further diminish the prospects of U.S. firms as their protected market was subjected to competition.

The government could also institute new technology programs with the objective of lowering launch costs and thus allowing U.S. producers to be more competitive in the international market. But only the most ambitious and expensive of these efforts--typified by the "new launch system" proposed in the President's 1992 budget--would be likely to lower costs enough to allow U.S. firms to match the prices offered by foreign competitors. The market for satellite launches is too small to justify such expenditures, which could run between $10 billion and $15 billion. If, however, the government developed a new lower-cost launch system for public purposes--for example, to support a major new space initiative--a secondary benefit could be to make U.S. firms more competitive in the commercial market.

The government could continue to use public procurement to increase the price competitiveness of U.S. producers of launch vehicles. One option would be to expand the policy of public procurement of launch services on "commercial" terms, by allowing managers of satellite and space science programs to contract for space launches and providing them with the budgetary support to do so. This option, however, would be unlikely to contribute substantially to the ability of U.S. producers to win launch contracts in the international commercial market.

A more aggressive stance would be to combine public procurement with programs for developing new launch vehicles, with the objective of lowering the cost of launch services. This approach would require significant federal spending, although some private investment could be expected. A likely consequence of such a program would be to create a single "national," but private, launch company. An early indication of a move in this direction is the current consortium of rocket motor producers financed by Advanced Launch System development funds.

CONDITIONS OF SUPPLY

Governments establish the capacity and technical capabilities of launch systems to meet public needs. As a by-product, they also determine the supply of space transportation available to the commercial market. The willingness of governments to invest in launch capacity is likely to lead to an oversupply of launch services in the commercial market for the next decade. National security remains the basic and most important motivation for these public investments in launch capacity. In recent years, however, beginning with the space shuttle and the Ariane systems, a new objective has emerged--that of gaining a share of the commercial launch market. Both systems were developed with the expectation of defraying a part of the cost of public space transportation by selling services to the private sector. Now other countries, from China and Japan, which have a limited annual launch capacity, to the Soviet Union, which possesses the world's most substantial launch capacity, are looking for a share of the commercial market. (For a description of the technology involved, see Box 2.)

Competitors and Strategies

The launch vehicles that are likely to be competitors in the commercial launch market of the 1990s are those capable of lifting payloads of 1,500 pounds to 4,500 pounds into geostationary orbit. Their payloads will predominantly be commercial communications satellites. The U.S. Delta and Atlas vehicles and the Chinese Long March vehicles can carry single-satellite payloads. The U.S. Titan 3 and the European Ariane 4 are each capable of carrying two medium or small-sized communications satellites. Dual launches offer a price advantage, but subject each payload to the possibility of delays caused by problems with its companion.[1] The Titan 3 and the Ariane 4 can also carry the largest commercial communications satellite, the Intelsat 6, as a single payload.

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1. In recent satellite launch bidding, Arianespace bid $40 million to carry a satellite as one of two on its Ariane 4, a dual-launch payload, while McDonnell Douglas bid $50 million to carry the same satellite on as a single payload on its Delta vehicle. Stephane Chenard, "The Long March to Launch Regulation," *Space Markets* (July/August 1990), p. 199.

Japan's H-II, when it becomes operational sometime in the mid-1990s, will offer service equivalent to that of the Ariane 4 and the Titan 3. The Soviet Zenit vehicle could by 1995 offer yet another carrier able to carry two payloads. Later in the 1990s, however, the Ariane 5, currently in development, with the capability of carrying three satellites, will replace Ariane 4. The Soviet Proton vehicle and the U.S. Titan 4 currently have this capability but neither is used as a commercial carrier. Table 1 lists the characteristics of the launch vehicles likely to supply the market during the 1990s.

The United States. The U.S. commercial launch industry is an integral part of the national space launch strategy. Procurement of launch vehicles and services by defense and civilian agencies has ensured that all three major families of launch vehicles will be available into the mid-1990s, as shown in Table 2. U.S. capacity likely to be available to the commercial market on an annual basis during the 1990s includes five single-payload McDonnell Douglas Deltas, four General Dynamics Atlases, and two dual-payload Martin Marietta Titan 3s. The diversity of the U.S. national launch capability--three separate expendable launch vehicles and the shuttle--provides multiple avenues to space for most payloads.[2] The cost of this diversity, however, is a sacrifice of economies of scale that might have been gained if there were fewer producers.

Because the commercial market is not large enough by itself to support its own facilities, U.S. producers must use government launching facilities for commercial launches. Private users pay the additional costs incurred by the government for employing these facilities. The facilities can be preempted by the government, however, a disadvantage for U.S. producers as compared with Arianespace, which grants priority to commercial customers. The priority given to government payloads is consistent with the intent that commercial demand would be subordinated to public needs in the event of a national emergency. Because of the potential constraints on both public and commercial launch operations, investment in additional facilities is receiving increased attention. Florida and Hawaii are currently ex-

2. White House press release, "U.S. National Space Policy" (November 16, 1989), p. 10.

BOX 2
Launch Services: Products and Technology

The provision of launch services includes producing launch vehicles, integrating the payload with the launch vehicle, launch operations, and, finally, placing a payload in a desired orbit. Launch services are differentiated according to the launch vehicle's ability to lift weight into a specific orbit, the reliability of the launch system, its schedule flexibility and, for the military customer, the system's resilience--its ability to continue launch operations after a launch failure.

Some satellites, including those of the communications satellite industry, the most prominent private consumer of launch services, and some government weather satellites require placement in geostationary orbit (GEO). Geostationary orbit is an orbit 22,400 miles above the Earth in which a satellite makes its journey around the Earth's equator in 24 hours. Since the Earth rotates once on its axis during this time, the satellite is stationary with reference to a point on the Earth. A variety of other satellites used for weather monitoring, remote sensing of the land and sea, electronic surveillance, and navigation and positioning, are placed in lower orbits from 90 miles above the Earth to 13,700 miles. Many of these satellites that are used to survey large parts of the Earth system--atmosphere, land, or seas--pass near the Earth's north and south poles in a "polar" orbit.[1]

Satellites placed in geostationary orbit are launched from west to east, while those placed in polar orbit are launched along the north-south plane of the Earth. Rockets are usually launched over oceans or uninhabited territory because space launches remain dangerous. The United States' major launch facility, the Eastern Space and Missile Center (including the Kennedy Space Center) on the coast of Florida, is well suited for geostationary launches, but less so for polar placements as the launch vehicle must start in a west to east path and then "dogleg" to the left into the north-south plane. The West Coast Space and Missile Center at Vandenberg Air Force Base in California is the United States' major polar launch site, permitting satellites to

1. John S. Lewis and Ruth A. Lewis, *Space Resources Breaking the Bonds of Earth* (New York, Columbia University Press: 1987), pp. 120-128, reviews and defines various useful orbits.

2. Department of Defense and National Aeronautics and Space Administration, *National Space Launch Program Report to Congress* (March 14, 1989), pp. 28 and 29.

be inserted directly into the north-south plane by launching them southward over the Pacific Ocean.[2] As Vandenberg is primarily a military installation, concerns have been expressed about the limitations that military priority might place on polar launches for commercial purposes--primarily launches of remote sensing satellites. If the United States were to invest in additional launch facilities, they should have ready access to both west-east and north-south launch trajectories.

Satellites are launched into geostationary orbit in a three-phase process. The first phase, from the Earth to low Earth orbit (LEO) requires a large rocket system. The second phase, powered by a smaller rocket system usually called an upper stage, moves the payload from LEO to the elliptical geotransfer orbit (GTO). The third phase involves the firing of a small engine at the highest point of the transfer orbit so as to round out the orbit into a geostationary orbit. Once in the proper orbit, a communications satellite uses small onboard rockets to maintain its position. A satellite's life is limited by the fuel it can carry to power these rockets. Launch systems that place satellites as close to their final orbits as possible preserve fuel for this purpose and allow the payload its maximum life.

Proximity to the equator, where the Earth's rotational momentum is greatest, grants a launch vehicle an additional lift and a potential cost advantage for GEO placements. For example, a rocket launched from the Ariane base at Kourou, French Guiana, provides 10 percent more lift than if it were launched from the U.S. Kennedy Space Center. Site advantage, however, is not seen as a major factor in the competition between Ariane and U.S. firms. Site location could be more important were the Soviet Union to enter the market from a near-equatorial location, such as the launch facility proposed at Cape York, Australia. Current Soviet launch facilities are substantially farther north than either the U.S. or European launch sites. The lift of the Soviet Zenit vehicle launched from the Cape York site to GTO would almost triple relative to its current launch site, moving it from a Delta class vehicle to the equivalent of a Titan 3 or Ariane 4.[3]

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3. United Technologies Company, "Cape York International Spaceport, Queensland, Australia" (undated).

TABLE 1. LARGE-CAPACITY EXPENDABLE LAUNCH VEHICLES SUPPLYING THE COMMERCIAL MARKET

Vehicle	Company	Maximum Weight to LEO (In pounds)	Maximum Weight to GTO (In pounds)	Past Reliability (In percent)
		United States		
Delta 2 (6925)	McDonnell Douglas	8,800	3,200	95[a]
Delta 2 (7925)	McDonnell Douglas	11,100	4,010	Untested
Atlas 2	General Dynamics	15,000	5,800	87[b]
Titan 3	Martin Marietta	28,000	10,000	88[c]
		Europe		
Ariane 4	Arianespace	15,400	9,400	89[d]
Ariane 5	Arianespace	42,000	13,000	Untested
		China		
Long March 3	Great Wall Industry Company	5,280	3,100	90[e]
Long March (CZ2-4L)		19,500	4,500	n.a.
		Soviet Union		
Proton	Glacosmos	46,000	5,280	More than 90[f]
Zenit	Glacosmos	34,500	9,900	n.a.
		Japan		
H 2	NASAD	17,600	8,000	Untested

SOURCES: Congressional Budget Office from National Aeronautics and Space Administration and Office of Technology Assessment.

NOTES: LEO = low Earth orbit; GTO = geotransfer orbit; n.a. = not available.

a. 19 of last 20 Delta launches of all types. Delta II (6925) has had 7 launches as of March 1990.

b. 33 of 38 geostationary launch attempts of Atlas Centaur.

c. 36 of 41 geostationary launch attempts.

d. The lift capacity of the Proton Vehicle to geotransfer orbit is lower because of the relatively northerly latitudes from which the vehicle is launched.

e. 18 of 20 including all Long March vehicle types as of January 1989.

f. 25 of 28 commercial (that is, nondevelopmental and nonpromotional) flights.

TABLE 2. PLANNED FEDERAL PROCUREMENT OF LAUNCH SERVICES AND VEHICLES

Vehicle/ Company	Purchaser	Number of Vehicles Under Contract or on Option	Contract Value (Millions of dollars)
Delta/ McDonnell-Douglas[a]	Air Force Medium Launch Vehicle	20 (through 1991)	650
		24 to 27 options (1994-2000)	n.a.
	National Aeronautics and Space Administration	3 (through 1995)	140
		9 options (1994-2000)	n.a.
Atlas/ General Dynamics[b]	Air Force Medium Launch II	11 (through 1995)	520
		4 options (1995-2000)	n.a.
	National Oceanic and Atmospheric Administration	3 (through 1995)	205
		2 options (1996 through 2000)	n.a.
	Navy Ultra-High-Frequency Satellite Program via Hughes	1 for 1991 9 options (through the 1990s)	700[c]
Titan/ Martin Marietta[d]	Air Force and Other Federal Users	55 vehicles to be equipped through 1995 and 41 launches to be conducted during the 1990s	14,600[e]

SOURCES: Congressional Budget Office; General Dynamics; General Accounting Office.

NOTE: n.a. = not available.

a. Congressional Budget Office estimate.

b. General Dynamics.

c. Includes estimated value of options.

d. General Accounting Office, *Cost Increases and Schedule Delays in the Air Force's Titan IV Program* (May 1990), p. 11.

e. Includes vehicle procurement, launch operation, research and development, and construction.

ploring the possibility of state support and funding of launch facilities for large expendable launch vehicles.[3]

The commercialization program has required the government to change its behavior as a buyer of expendable launch vehicles. This change was intended to affect the performance of U.S. suppliers, and has succeeded in doing so. The traditional government approach to procurement led firms to bid for orders in small quantities rather than submitting lower bids for larger commitments. Recent changes in procurement practices that shift the focus from procuring vehicles to procuring launch services require the contractor to accept responsibility for the entire launch process as well as the construction of the vehicle. By moving NASA, other civilian, and even some military payloads to a service basis, the government makes its requirements complementary to those of the commercial market, permitting launch service providers to standardize their procedures and thus to benefit from economies of scale in launch operations.

The procurement-of-services strategy has been applied most aggressively by the Navy in purchasing 10 ultra-high-frequency communications satellites from the Hughes Corporation, to be delivered on-orbit. Hughes has contracted with General Dynamics to provide eight launches during the first half of the 1990s at a cost of $700 million.[4] General Dynamics claims that its Atlas 2 vehicle can place a satellite in orbit at a cost per pound 60 percent less than that of the Atlas 1 of the 1960s. Twenty percent of this reduction is attributed to the new commercial practices.[5] Quality and process control systems have been substituted for more expensive direct federal oversight, reporting, and documentation for each vehicle produced. Where practical, commercial standard parts and materials have been substituted for more expensive military standard components.

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3. See, for example, Spaceport Florida Authority, *Annual Report* (November 30, 1990).

4. *Aviation Week and Space Technology* (June 4, 1990), p. 69.

5. Testimony of the Commercial Space Transportation Advisory Committee (COMSTAC) Subcommittee on Procurement before the Subcommittee on Space Science and Applications of the House Committee on Science, Space and Technology (November 9, 1989), p. 3.

The U.S. government strategy emphasizes improving the technologies for future use rather than increasing the current market share of existing vehicles. Heavy support has been given to developing the space shuttle and Titan 4 programs in the last several years, and these will continue to receive funding through the mid-1990s.[6] Neither vehicle will carry commercial payloads. The government also maintains an ongoing research and development program in basic rocket technologies. The President's 1992 budget proposes a "new launch system" that would draw upon the recent efforts of NASA (to develop a cargo vehicle derived from the shuttle system) and the Department of Defense (to develop the Advance Launch System program) in order to build a new vehicle by the late 1990s. The budget proposes initial funding of $350 million, split evenly between NASA and DoD. The program could ultimately cost $10 billion to $15 billion. Developing new rocket components, such as engines, that may result from this program, could improve the commercial prospects of the U.S. industry if the technology is transferred to privately operated systems.[7]

A variety of longer-range programs, such as development of the National Aerospace Plane, are not expected to affect launch capabilities in the next 20 years. The Augustine Report has been the most recent of a series of studies to recommend developing new vehicles for the public sector, but says little about how that development could be integrated with private investment goals.[8]

The commanding role assumed by the federal government in space transportation, and the limited prospects of the nongovernmental market, diminish the private sector's incentives to invest in long-run improvements in vehicle technology. Private investment in large-

6. Spending on the Titan 4 program, begun in 1984, will by 1995 include over $2.6 billion in research, development, test, and evaluation support, to provide the Air Force and the intelligence community with an alternative to the shuttle for launching heavy satellites. See General Accounting Office, *Cost Increases and Schedule Delays in the Air Force's Titan IV Program* (May 1990). The space shuttle program production and operational capability account was funded at $1.1 billion in 1990, including funds for the $1.7 billion Advanced Solid Rocket Program designed to increase the shuttle's capability during the mid-1990s. National Aeronautics and Space Administration, *Budget Estimates Fiscal Year 1991*, (date) vol. 1, p. sf.1-1.

7. National Aeronautics and Space Administration Advisory Council, *Report of the Task Force on Space Transportation* (December 1989), p. 8.

8. National Aeronautics and Space Administration, *Report of the Advisory Committee on the Future of the U.S. Space Program* (December 1990), pp. 32-34.

capacity launch vehicles has mainly taken the form of purchasing vehicles in large quantities so as to reduce costs and become more competitive in the public and private markets. General Dynamics has reportedly invested $400 million in its commercial operation, largely to produce 61 Atlas vehicles for use during the 1990s.

Europe. The Ariane rocket is the world's leading commercial launch vehicle, accounting for over half of the market through the mid-1990s. The European Space Agency developed the Ariane technology and maintains responsibility for investment in launch facilities and new vehicles. The current model, the Ariane 4, is scheduled to be launched nine times a year from an equatorial site in Kourou, French Guiana.

The Ariane rocket is operated by Arianespace, a mixed enterprise that includes private aerospace firms, banks, and the Center National d'Etudes Spatiales (CNES), France's public space agency. Only recently have the positions of Director General of CNES and chairman of Arianespace not been filled by the same individual. Arianespace functions as a commercial provider--marketing services, procuring rocket components from private firms (the same aerospace firms that have an ownership position in Arianespace), and assuming responsibility for launch operations.

Arianespace's newer facilities and technology give it an advantage over its U.S. competitors. Arianespace aims to operate profitably, and industry observers believe it can do so if it wins 12 payloads a year. Like U.S. firms, Arianespace buys blocks of vehicles; its latest commitment, made in 1989, was for 50 Ariane 4 vehicles worth nearly $3 billion.

Arianespace's near-captive market, consisting of the European Space Agency and the French government, is smaller than the U.S. government market because Europe as an entity has no military satellites. The system as a whole thus depends more on commercial demand to achieve economies of scale. The goal of obtaining commercial launches has led Arianespace to grant these payloads priority, creating incentives to control cost and operate more efficiently. According to its international competitors, Arianespace's zealous pursuit of markets had led it to engage in unfair trade practices.

The complex web of relations among Arianespace and its owners creates both advantages and disadvantages. For example, ample room exists for shifting costs and expenses, opening the possibility of marginal subsidies in current operations. The multinational character of Arianespace's ownership and operation offers an opportunity to exploit currency mixes in cost accounting and pricing. The direct ties with governments raise a question whether side conditions--for example, rocket technology transfers--are used to win launch contracts.[9] However, because the European Space Agency is a multinational agency it must disperse its contracts among suppliers from different countries on the basis of a "fair return" for each, which may not be consistent with minimizing costs.

An uncertainty in Ariane's future is the commercial competitiveness of its Ariane 5 rocket. The Ariane 5 and associated facilities currently in development are estimated to cost between $3.5 billion and $5 billion, including over $0.5 billion for a new launch pad and support facilities. The vehicle is larger than the Ariane 4 because it has been designed as a manned spacecraft booster. Its larger size and improved performance have led Arianespace to predict that a fully loaded Ariane 5 will orbit a satellite at a cost 40 percent less than that of the Ariane 4. Yet to be answered is the question of whether there will be a market niche for a rocket that can carry three medium-sized satellites, or one large and one medium-sized satellite. Ariane 5 is also likely to increase the size of Arianespace's captive market, since it is to be the booster for Hermes, Europe's manned spacecraft currently in development. Thus, by the year 2000, Arianespace could face combining private launches with an urgent public agenda, and juggling manned and unmanned operations--the same problems that currently bedevil U.S. launchers.

In the final analysis, while the sales generated by Arianespace contribute to European exports and help defray the cost of the launch system, the commercial revenues are insufficient to cover total costs including vehicle development. To justify the expenditures on Ariane, some additional public benefit must be asserted.

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9. Stephan Chenard, "The Long March to Launch Regulation," p. 193, cites the case of tying Brazil's decision to buy Ariane launches to the transfer of rocket engine technology from Europe to Brazil.

China. China also currently supplies the commercial launch market. Long March, the Chinese vehicle, is a single-payload carrier, equivalent to the Delta or Atlas depending on its configuration. Since 1970 the Long March has successfully flown 24 times and failed twice, most recently in 1976. The vehicle was developed as part of China's military effort. The Great Wall Industrial Corporation markets Long March launch services to the West.

China's motivation in entering the commercial market is to earn hard currency. It has pursued this objective by offering low prices, down to half the prevailing rate. The Chinese contend that these prices reflect their costs, but Western competitors counter that the nonmarket character of the Chinese economy renders this claim meaningless.

The Administration reached an agreement with China on launch prices and quantities in 1989. Following very low introductory prices for two launches, China agreed to offer market or "par" prices for its services, and to fly no more than nine payloads over six years. So far, China has launched one satellite of the nine agreed on, but has at least three launch contracts outstanding. U.S. launch companies along with Arianespace have charged that the Chinese have continued to offer below-market prices in winning these bids. In the case of two Australian satellites, the Chinese bids were priced at about a third of those for the U. S. Delta and Atlas. The differences were reduced in part by higher insurance rates for launching on Chinese vehicles.

Congressional action during 1990--the Export Facilitation Act of 1990 (H.R. 9653)--would have superseded the 1989 agreement and required a Presidential waiver for U.S. manufactured satellites to use Chinese launch services based on a finding that China was living up to the terms of the 1989 agreement. The President, however, did not sign the bill and the Congress did not attempt to override his pocket veto.[10]

The Soviet Union. Like the United States, the Soviet Union has developed its launch capacity in the cause of national security. Like

10. David P. Radzanowski and Marcia S. Smith, "Space Launch Options" (Congressional Research Service, December 17, 1990), p. 8.

China, the USSR brings its excess capacity to the commercial market to earn hard currency.

The Soviet production of expendable launch vehicles is a large-scale operation, in contrast to that of the rest of the world. Of the 101 successful launches conducted in 1989, 74 were Soviet.[11] If, as indicated by current plans, the Zenit vehicle--a rocket proposed for commercial sale under one plan--replaces the Soyuz in the Soviet fleet, the annual production rate for these rockets could be in excess of 40. By comparison, the highest annual rate planned elsewhere is 10 to 12 for the McDonnell Douglas Delta. In general, non-Soviet producers provide low-volume launch services using more technically sophisticated launch vehicles, and their payload integration and launch operations are more labor intensive. The Soviet approach is the opposite: high-volume production of relatively unsophisticated vehicles and automated launch operations.[12] An irony of the Soviet advantage in launch cost is its roots in lower technology and less reliable satellites. Despite the large number of Soviet launches, the United States and the Soviet Union have had roughly the same number of satellites on orbit for the last 20 years. The combination of low launch costs and long-lived satellites will ultimately produce the lowest-cost satellite service.

Despite the dramatic improvement in East-West relations, there has not yet been any export of high-technology commercial communications satellites for launch in the USSR. The Soviets have expressed interest in ventures that would sell Soviet vehicles to third parties and permit launches from Western nations like Brazil or Australia. Currently under consideration is a privately financed spaceport at Cape York, Australia. The proposal includes a role for USBI, a subsidiary of United Technologies Company, as an operating contractor and perhaps in the future as an equity investor. The Australian operator hopes, like China, to penetrate the market by offering low prices--$70 million to $80 million for services currently on the market at $100 million to $140 million.

11. Congressional Research Service, *Space Activities of the United States, Soviet Union and Other Launching Countries/Organizations: 1957-1989* (March 2, 1990).

12. *Space News* (January 29-February 4), p. 1.

The Administration has indicated that it will permit USBI to participate in the Cape York venture, and will eventually permit launches of U.S.-manufactured satellites there, provided the operation conforms to requirements yet to be developed, including rules of the road for pricing launch services. Under its preliminary plan, the Cape York Space Port Authority would begin operations in the mid-1990s and expand to five single-payload launches by the late 1990s. The Soviet vehicle proposed for use, the Zenit, would be capable of carrying two medium-sized communications satellites on a single launch. The generally weak demand for launches that is projected during the late 1990s could force Cape York to shift to double launches. If the United States or Europe were to be successful in negotiating a single payload restriction, or in requiring the Soviet Union to raise the prices of its launch vehicles, the Cape York venture would be less attractive.

Japan. Japan is in the process of developing its first independent large-capacity vehicle, the H-2. Japan's National Space Development Agency (NASDA) is publicly funding development at a cost of $1.4 billion. Originally scheduled for 1992, the H-2 may not fly until the mid-1990s because the Japanese effort has been beset by problems in engine development--an area in which Japan is decidedly behind the United States.

Japanese intentions with regard to the commercial market are unclear. The H-2's launch costs are projected to be higher than the current price of Ariane 4. H-2 could be even less competitive by the mid-1990s when Arianespace plans to reduce its costs, and when China and the Soviet Union are likely to be competitors. Nevertheless, NASDA and a group of Japanese companies led by Mitsubishi have announced their intention to form a consortium similar to Arianespace with the objective of serving Japanese public demand and testing the commercial market.[13] Another possibility would be for the Japanese to cooperate with McDonnell Douglas in providing a second stage to upgrade the Delta vehicle.

13. *Space News* (February 19-25, 1990), p. 3.

Capacity, Cost, and Price

The limiting factors on launch capacity for each of these systems are the annual vehicle production rate as determined by production facilities or the annual launch rate as determined by the capacity of launch pads (see Table 3). A conservative estimate sets launch capacity in the mid-1990s at 30 medium-sized communications satellites, as compared with the current capacity of 20 to 25 payloads. It should be emphasized that launch failures can restrict capacity at any time, as shown by the failure of the Ariane 4 in 1990. Arianespace had planned nine launches for 1990, but may not be able to execute more than five.

TABLE 3. ESTIMATED NUMBERS OF LAUNCH VEHICLES AVAILABLE TO THE COMMERCIAL MARKET, 1995

National Origin	Type of Vehicle	Number
	Single-Payload Carriers	
United States	Delta	4
United States	Atlas	4
China	Long March	2
	Dual-Payload Carriers	
United States	Titan III	2
Europe	Ariane 4/5	6/4
USSR/Australia	Zenit	5
Japan	H-2	2

SOURCE: Congressional Budget Office.

No great disparities in cost are evident among leading producers in the United States--General Dynamics and McDonnell Douglas--and in Europe. The U.S. Titan 3 does not appear to be competitive even as a dual launcher. The recent entry of the Chinese Long March into the market at very low prices suggests either substantial direct subsidies or lower costs, the latter attributable to a lower-technology vehicle and low wages. The character of the Chinese economy may have forced the wage levels of engineering and technical labor below the world market level. The even lower costs suggested by Soviet offers to fly commercial payloads may also reflect this economic factor. Yet Soviet production rates, experience, and technology suggest that the USSR may be capable of providing commercial launch services at a lower real economic cost. Service prices for the vehicles competing in the commercial market are presented in Table 4.

TABLE 4. SERVICE PRICES OF LAUNCH VEHICLES
(In millions of 1989 dollars)

Vehicle	Launch Price
United States	
Delta 2	40-50
Atlas 2	60-85
Titan 3	130-140
Europe	
Ariane 4	100-110
China	
Long March	30-60
Japan	
H-2	n.a.
Soviet Union	
Proton	30-65
Zenit	80

SOURCE: Congressional Budget Office, from National Aeronautics and Space Administration.

NOTE: n.a. = not available.

Characteristics of Low-Volume Producers. The low annual launch rates of the non-Soviet producers suggest that their vehicle production and launch operations are very labor intensive, resembling a construction rather than a production activity. In most cases, the cost of plant and equipment is paid by the government, although U.S. firms have recently invested in retooling and launch-pad improvements--for the most part, in expectation of government business. The cost of new launch facilities and equipment is indicated by the estimated $800 million necessary for the Cape York Space Port.

Given available production and launch facilities, unit costs fall as the number of launches increases, even for low-volume producers. These cost decreases result primarily from spreading fixed costs over a larger production base, at both the contractor and the subcontractor levels. In the case of U.S. launch vehicles, the relation between unit costs and the annual rate of vehicle production is clear. For example, an Aerospace Corporation study conducted in the mid-1980s estimated that the unit costs of an eight-unit run of Delta vehicles would average only 69 percent of those of a two-unit run. Comparable figures of 65 percent and 59 percent were reported for the Atlas and Titan vehicles, respectively.[14]

Characteristics of High-Volume Producers: the Soviet Case. The Soviet Union produces launch vehicles at a higher rate than any other country, and is likely to continue to do so even with lower defense requirements. In comparison with Western vehicles, the Soviet vehicles represent "low" technology, and the lift capacity of the vehicles far exceeds that required to deliver the payload into orbit. Little information is available about Soviet production technology. Soviet launch operations are known to be more automated than in the West. Moreover, Soviet vehicle production and launch operations enjoy a substantial advantage in cumulative experience, or learning--a factor associated with lower cost in the aerospace industry.

The cost of Soviet launch services might increase, however, if the economy became more market-oriented. The wages of Soviet workers

14. E. Blond and W. Knittle, *Space Launch Vehicle Costs*, prepared by the Aerospace Corporation for the Department of Transportation, Office of Commercial Space (1984), chap. 4.

would have to be adjusted upward to cover the housing, food, and medical subsidies they now receive. Moreover, the real resource costs of Soviet launch activities, a sector traditionally favored by the central planners, are likely to have been held down relative to what the costs would be in a more consumer-oriented economy. If demand was permitted to expand along the lines favored by individual consumers, the domestic price of engineering and skilled labor could be expected to increase as new producers of consumer goods bid for these skills. Higher wage costs would in turn increase the ruble costs of vehicles and launch operations. For the international commercial consumer of launch services, however, a part of these cost increases could be offset by a fall in the exchange value of the ruble.[15]

CONDITIONS OF DEMAND

The total demand for launch services includes commercial, scientific, and military payloads. Commercial demand is usually defined as including civilian communications satellites and a small number of other satellites. This demand is governed by the growth in demand for telecommunications services and the cost of satellite systems relative to other technical alternatives. Government launch demand is driven by the willingness of governments to spend on space activities.

Captive Markets

All of the major competitors in the space launch industry have captive markets in their respective public sectors--that is, markets not open to the other competitors. The largest of these captive markets are those of the United States and the Soviet Union, which include military and other public-sector payloads. Arianespace also enjoys a captive market consisting of two annual European Space Agency launches as well as French government payloads. In addition, Ariane's competitors claim

15. Jan Vanous, in "Investing in Eastern Europe: Opportunities and Obstacles," *DRI/ McGraw Hill Review of the U.S. Economy* (December 1989), pp. 13-19, discusses in a broad context the cost of engineering and technical labor in the Soviet Union and Eastern Europe, and the relation of anticipated changes in exchange rates to these costs.

that European public postal, telegraph, and telephone companies show a strong preference for Ariane.

Launch demand in these major captive markets is governed primarily by the demand for public goods requiring space activity, as expressed in the budgets for civilian and military space activity. The entry of new launch providers in other countries will shift some payloads from the present commercial market to new captive segments under a fly-the-national-flag rationale. For example, India uses its national capacity to launch satellites that would otherwise be in the international commercial market.

The Commercial Market

The forecasts of commercial demand for satellite launches shown in Table 5 are in broad agreement as to the market outlook. Current demand for launch services is around 20 payloads a year, and will stay at this level through 1993 or 1994. In the second half of the 1990s, the consensus is for lower demand--that is, between 10 and 15 launches annually. Communications satellites dominate this market, as indicated by Arianespace's estimate that about 70 percent of its launches during the 1990s will consist of telecommunications payloads. Observation and meteorological satellites split the remainder of the projected demand evenly with scientific payloads.[16]

Telecommunications services represent the most significant final market for commercial launch services. While real growth is expected to continue in this market, especially in the international segment, the major beneficiaries of the growth are likely to be competing technologies that do not require satellites.The traditional satellite communications market is being pressed by technical competition from fiber optic cable systems. In the voice communication segment, accounting for 80 percent of all telecommunications services, international fiber optic capacity is expected to grow by 40 percent a year through 1997, while demand increases no faster than 20 percent

16. *Arianespace Newsletter* (February 1990), no. 48.

TABLE 5. FORECASTS OF COMMERCIAL DEMAND FOR SATELLITE LAUNCHES IN THE 1990s

Forecaster	Number of Launches
National Aeronautics and Space Administration, Office of Space Flight (June 1989)	11 to 21 annually in 1990 through 1994, 10 on average in 1995 through 2000
Center for Space Policy (November 1989)	17 to 25 annually through 1993, less than 10 in 1994 through 2000
Euroconsult (November 1989)	15 telecommunications satellites annually, 3 additional earth observation satellites annually, in 1989 through 2000
General Dynamics (November 1989)	13 payloads annually in 1990 through 1998
Arianespace (February 1990)	17 to 25 annually in 1992 through 1996, 15 to 19 annually in 1996 through 2001
United Technology Corporation (February 1990)	14 to 24 annually in 1993 through 1996, 13 to 16 annually in 1997 through 2000
U.S. Department of Transportation, Office of Commercial Space (June 1990)	17 to 20 annually through 1994, 12 to 17 annually in 1997 through 2000

SOURCE: Congressional Budget Office.

annually. Prices are expected to fall as a result, leaving satellite options, where costs are not expected to fall, in a difficult position.[17]

Part of the slack could be taken up by new commercial satellites catering to land-mobile communications services, direct-broadcast TV, corporate data transmission, and navigation services. For example, Motorola's proposed 77-satellite lightsat cellular telephone system could add the equivalent of 10 payloads to the demand forecast for the late 1990s. But even allowing for some growth in these areas not reflected in the projections in Table 5, the commercial demand for launch services should at best be flat during the 1990s.

17. Department of Commerce, *U.S. Industrial Outlook 1990* (1989), pp. 31-6.

POLICY OPTIONS

During the 1990s, the prospects of commercial launch vehicle makers will depend, in part, on federal policies governing trade and technology. Policymakers will also have to take into account issues that extend beyond the welfare of the launch industry, including the future space launch requirements of the public sector, the interests of foreign policy, and the consequences of space launch policies for other U.S. industries. In some instances, trade-offs will have to be made between the health of the commercial providers of launch vehicles and other national objectives.

Trade Options

The choice facing the United States in the trade arena is between freer trade and more explicitly managed trade. In the field of space commercialization, a freer trade stance would involve permitting China, the Soviet Union, or other new entrants to launch U.S.-manufactured satellites. Prices lower than those currently available on the market would be accepted regardless of their relation to costs and their chilling effect on the U.S. share of the commercial launch market.

A negotiated trade stance would discourage new entry by restricting the carriers on which U.S.-made satellites could be launched or by forcing new entrants to charge prices comparable to those offered by Arianespace and the U.S. providers. To this end, the United States and Europe could conclude agreements effectively limiting the international launch market to Arianespace and the current U.S. producers.

Freer Trade. The United States may wish to pursue a policy of "freer" trade in the international launch market. It could open parts of the U.S. captive market, such as civilian applications satellites and space science, to all competitors. It could also allow U.S. satellites manufactured for the commercial market to fly on the lowest-priced vehicle, without regard to its cost of production or the effect on U.S. vehicle manufacturers. A completely free trade strategy is not within the feasible set of possibilities in that the imperfections of the international launch market seem more or less permanent. The U.S. and other governments currently operating launch systems to deploy national security satellites are not likely to cease these operations, or to cease providing research and development support to private or quasi-private national launch systems.

Under a freer trade policy the share of some firms in the world commercial market would fall. U.S. firms would be more exposed than Arianespace, with its direct link to public funding. Moreover, European spending on the Ariane 5 with its potentially lower launch costs would make Arianespace more competitive. Consequently, the share of the market taken by new entrants would probably be at the expense of U.S. rather than European providers. U.S. firms might continue to supply foreign prime contractors with components, in response to changes in market conditions provoked by a freer trade policy.

Launch customers would generally benefit from lower prices for launch services. U.S. satellite manufacturers, who are well established in the international market, would not share directly in the vehicle manufacturers' loss of markets, although some observers of the industry have argued that launch services and satellite production contracts are tied together in such a way that lost launch services would eventually lead to lost satellite contracts. It should be noted, however, that the rise of Arianespace to prominence as a launch provider has not been tied to substantial growth in Europe's satellite market share. Moreover, the stronger the U.S. position on free trade in launch services, the more consistent would be a U. S. effort to open foreign telecommunications satellite contracts to U.S. bidders.

In the U.S. public sector, it is difficult to assess the costs of a freer trade policy. On one hand, opening some U.S. public satellite launches to foreign competition could lower the price of those launches. On the other hand, U.S. producers of launch vehicles would suffer: the loss of public-sector launches in combination with fewer commercial space launches would cause U.S. producers to lose scale economies, perhaps forcing up costs for the part of the public demand that would still be captive. National security requirements limit the benefits of freer trade most in the largest expendable launch vehicle size classes, where the potential savings of competition are greatest because Martin Marietta's Titan 4 faces no domestic competitor.

Broader political and economic concerns would also be involved in adopting a freer trade policy. The issue of Soviet or Chinese entry into the world market is a political and strategic concern, as well as an economic issue. In the longer view, the Soviet and Chinese systems both face the need to become more open. Additional export earnings would support a move in this direction. Moreover, as evidenced by the position of some U.S. aerospace firms in the debate over whether or not to grant export licenses to fly Hughes satellites on Chinese vehicles, restricting new entry in the launch market could provoke retaliation in related aerospace markets that, in cases like jet aircraft, are potentially larger U.S. export markets than launch services.

Negotiated Trade. The focus of a negotiated trade policy would be on restricting new entry into the commercial market and working out a set of "rules of the road" for competition between Arianespace and the U.S. launch companies. An agreement between the United States and Europe would determine the set of costs to be included in launch prices, and also discourage nonprice concessions. In the short run, new entry would be discouraged by denying export licenses for satellites to be launched on the vehicles of new entrants. While a negotiated trade policy would focus formally on behavior, its implicit goal would be to maintain current U.S. and European market shares, as indicated by the initial agreement with China that established a quota, in all but name, of nine launches through 1994.

Incumbent launch providers would certainly gain from supply restrictions. Conversely, satellite launch customers would pay higher launch prices. New entries would be discouraged, to the extent that new entrants are drawn by the prospect of earning hard currency in the commercial market. In that case, the creation of new capacity would slow, and its contribution to current excess supply would diminish. However, entry into this market seems largely independent of the prospect of commercial success.

A negotiated trade policy could lead to price collusion between Arianespace and U.S. providers. Trade regimes based on quotas would certainly encourage higher prices. If unchecked by either the threat of new entry or U.S. domestic policies encouraging competition, U.S. vehicle producers could charge higher prices--not only in the commercial market segment but also in the captive U.S. government market segment. The most desirable solution from a U.S. point of view may be to find a negotiated trade solution in the international market that maintains the pressure on U.S. producers to lower costs and in doing so reinforces domestic competition policies.

What implications would a negotiated trade policy have for U.S. satellite manufacturers? The origin of Arianespace is suggestive in this regard. The refusal of the United States to launch a European communications satellite, Symphonie, that at the time would have undermined U.S. policy opposing regional satellite communications systems that were potentially competitive with Intelsat, is usually credited as a factor leading to the development of Ariane.[18] Launch market restrictions that encourage customers to turn to new entrants in satellite manufacture from Japan, India, the Soviet Union, or South Korea would ultimately be detrimental to the present leaders in the industry, primarily U.S. firms. Since 1988, U.S. producers have exported 14 communications satellites with a market value of $1.6 billion. In this respect, losses in satellite sales could offset trade gains in launch services.

A negotiated trade policy raises another question--whether the U.S. industry can sustain its position without a strong effort to lower its costs by improving technology or developing new vehicles. In the mid-1990s, Ariane 5 may lower Arianespace's costs and make its dual-launch capacity all the more attractive. The U.S. dual-launch entry, Titan 3, is already overmatched by Ariane 4 in the view of most industry observers. Neither Delta nor Atlas is expected to show significant additional reductions in cost by the mid-1990s. Thus, under a cost-based trade regime, Arianespace might be able to increase its share of the market at the expense of Delta and Atlas without departing from the rules of the road.

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18. Office of Technology Assessment, *International Cooperation and Competition in Civilian Space Activities* (July 1985), p. 125.

A negotiated trade policy also carries with it many problems of administration. An essential element in trade guidelines or restrictions would be an internationally recognized set of costs to provide a basis for pricing launch services. Establishing the guidelines could be very difficult. All of the launch systems currently on the market have been developed with government investment. The U.S. and European launch vehicles achieved their success with the aid of direct governmental subsidies. New entrants would demand the right to do the same, as evidenced by the U.S. agreement with China that permitted low introductory prices for the maiden commercial launches of new vehicles.

The nonmarket character of the Chinese and Soviet economies presents further difficulties, most pronounced in the Soviet case where--despite the absence of working markets--annual launch volume, cumulative experience, and a low-technology approach suggest that the Soviets are actually the low-cost provider. Even producers who are required to break even in the long run in a competitive market may offer below-cost bids to fill a second slot on a dual launch, or to establish a relationship with a new customer. Finally, the existing close relationships between governments and their national launch companies leave considerable room for tacit agreements that will make a deal more attractive to a particular buyer.

Another concern would be to develop machinery for enforcing rules of the road. Export controls created for other purposes, such as preventing transfers of technology that compromise national security, may not be appropriate for strictly economic objectives. The customary mechanism used for addressing trade issues--filing a complaint with the United States Special Trade Representative under section 301 of the Trade Act--is cumbersome, and in the only case in this industry so far has proved ineffective.

In the broader geopolitical and economic arena, a negotiated trade policy that excluded Soviet and Chinese entry would have opposite effects to those of the freer trade alternative. It would not provide those countries with any incentive to liberalize their economic practices in order to earn hard currency. Finally, a negotiated trade policy in the commercial launch market would conflict with the general U.S. stance of support for lowering trade barriers in all markets.

Options for Developing New Technology and New Systems

Recent studies have focused intensively on the technical choices confronting the United States in developing new launch systems.[19] The costs of space launches could be cut dramatically if investments were made in new technologies and systems. For example, by one estimate the U.S. Air Force's Advanced Launch System proposal could reduce the cost of space launches to an eighth of the current level, if the Congress was willing to invest over $15 billion and if the demand for space launches was sufficient to justify high launch rates.[20] An effort focused only on propulsion could cost $5 billion during the 1990s, and reduce costs by perhaps one-half.[21] The cost of the "new launch system" proposed in the 1992 budget could range between $10 billion and $15 billion.

Investments in new technology could improve the competitiveness of U.S. producers, perhaps even to the point of maintaining or expanding their share of the international market under a freer trade regime. The projected size of the commercial market, however, provides neither private firms nor the public sector with sufficient incentives to make these investments. At best, gains in the commercial market would offer a subsidiary benefit to the primary gain from new investment, a reduction in the cost of public-sector space launches. The Office of Technology Assessment concluded on this score that the large investments necessary to lower launch cost would only be justi-

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19. Office of Technology Assessment, *Access to Space: The Future of U.S. Space Transportation Systems* (May 1990), summarizes a two-year, five-part, ambitious effort to present and analyze the technology options open to the United States in space transportation. Technology program options are also presented and analyzed in Department of Defense and National Aeronautics and Space Administration, *National Space Launch Program Report to Congress* (March 14, 1989); National Aeronautics and Space Administration Advisory Council, *Report of the Task Force on Space Transportation* (December 1989); and National Center for Advanced Technologies, *National Rocket Propulsion Strategic Plan* (February 1990).

20. NASA Advisory Council, *Report of the Task Force*, p. 9.

21. See National Center for Advanced Technologies, *National Rocket Propulsion Strategic Plan* (February 1990), p. 13, for program cost, and NASA Advisory Council, *Report of the Task Force*, p. 9, for cost reduction.

fied if public demand increased far above its current level.[22] Programs such as the Strategic Defense Initiative and the Space Exploration Initiative could, according to the OTA report, increase the number of U.S. launches to four or five times above the current level. The Congress has not approved programs of this type, however.

Institutional Options

Commercialization of the launch industry is currently delivering a set of benefits broadly consistent with the policy's objectives. U.S. firms have garnered a share of the international market. The cost of launch vehicle services to the government is arguably lower than it would have been if all the launches were provided in the traditional contractual mode. One option would be to continue down the current path. Alternatively, concern about the competitiveness of U.S. producers in the commercial market of the mid-1990s and beyond could suggest new options that would directly involve the federal government in the commercial launch market, perhaps in a mixed enterprise similar to Arianespace.

Procurement and Competition Policy. Space commercialization in the launch vehicle area has seen a shift in federal policy to procuring launch services rather than vehicles. In combination with withdrawing the shuttle from the commercial market, this change in procurement has created a supply-side pressure on launch providers to lower costs and increase efficiency. An option open to the federal government is to expand its commercial procurement policy.[23] This could include a goal of launching all unmanned cargo under commercial launch service agreements. Innovative procurement strategies could be adopted that would disperse purchasing authority among the ultimate federal (or federally funded) launch customers, perhaps through a launch voucher system.

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22. Office of Technology Assessment, *Access to Space*, p. viii.

23. The Space Transportation Services Purchase Act (H.R. 2674), introduced in June 1989, is an example of one such proposal.

Procuring launch services rather than launch vehicles shifts responsibility from the government to the contractor. U.S. producers benefit from increased flexibility and fewer reporting requirements, as well as the opportunity to standardize their commercial and federal market operations. In combination, these factors may be translated into cost reductions and lower and more competitive prices in both markets. Significant portions of the defense market, and a part of NASA's anticipated requirement, are still filled through traditional vehicle procurement and subsequent government launching of these vehicles. Most notably, the Titan 4 program continues to operate in a traditional mode.

A cost of moving from procuring traditional launch vehicles to launch services is the loss of a capability for independent military launch operations. This cost is diminished to the extent that the current capability consists of contractors' teams, and the military monitors, rather than launch operations directly executed by the military. Commercial procurement alone may be insufficient to generate competition and gains in efficiency if no gains are to be had in the commercial market, or if the service provider continues to be the sole source over the long run. In the latter case, one option is to combine launch services procurement with industrywide support programs for new technology to make entry into the industry easier. Variants of the Advanced Launch System program technologies could move the industry in this direction.

The "shuttle only" space launch strategy centralized decisionmaking and service in space transportation. The move back to a diverse national launch strategy, including the shuttle and several varieties of launch vehicles, has widened the field of supply-side choices available to launch customers in parts of the captive and the commercial markets. A large segment of scientific demand, primarily that funded by NASA, is still bound to the shuttle and still subject to shuttle delays. One proposal made to address the problems of centralized decisionmaking and the backlog of payloads is to issue launch vouchers to science project managers that would be paid to launch providers and redeemed by the federal government.[24]

The principal aim of such a procurement program would not be to stimulate commercial sales of launch vehicles, although it would have this effect. Allowing the ultimate consumer of launch services--the space scientist or institution--choices beyond the shuttle might stimulate technical innovation in the launch vehicle industry, particularly in developing unmanned payload carriers capable of carrying experiments to orbit and returning them to Earth. Broadening competition in the public sector would reinforce and complement competition in the commercial market.

Decentralizing decisionmaking in space transportation could result in further, but probably temporary, expansion of capacity. Empowering the managers of small and medium-sized science payloads to purchase launch services would open opportunities to a number of new firms. Some of these ventures would fail but others would succeed. While competition would push prices down, some economies of scale from multiple-unit procurement could be lost. The prospect, however, that competing firms would combine their payloads, or that buyers might band together to submit joint orders, could offset these losses.

A National Launch Company. The United States could create a national launch company similar to Europe's Arianespace. The option would involve consolidating existing U.S. launch vehicle producers and their supplier bases into a single entity, which initially would market the current fleet of U.S. launch vehicles. The company would use federal research and development programs to develop the next generation of components and vehicles. Through federal procurement, the company would order new equipment in a volume large enough to achieve economies of scale. The company could be an independent entity, but federal ownership of part of the stock would be convenient if the government was to help in financing new facilities or provide initial operating subsidies.

24. Molly K. Macauley, "Launch Vouchers for Space Science Research," Resources for the Future, Discussion Paper ENR89-04 (February 1989), pp. 3-7.

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A national launch company would have several advantages. One of the benefits of commercialization has been the incentive provided to U.S. firms to reduce the costs of space launches. A national launch company would preserve this motivation in the face of foreign competition with its improved vehicles and government subsidies. But the gains of domestic competition, achieved by competitive bidding in the public-sector market, would be lost. Part of this loss could be offset in the longer term (perhaps by the late 1990s) through larger-volume federal orders that would permit economies of scale.

A national launch company could also help producers anticipate the direction in which the U.S. industry is moving. NASA and the Defense Department are encouraging engine producers and prime contractors to cooperate in exploring new systems and technology with the use of federal R&D funds. Unless new public support is forthcoming in the mid-1990s, one or two of the current U.S. producers may abandon the commercial market. Some observers argue that Martin Marietta has already done so, leaving the United States without a dual-payload carrier in the commercial market. While federal procurement could maintain all three of the current vehicle families, doing so would mean turning the clock back to the pre-shuttle era when a single producer monopolized each size class. Paradoxically, the only way to preserve the benefits of competition may be to consolidate the industry so that the prospect of gain in the commercial market remains a force for cost reduction and efficiency in supplying the public sector.

A significant disadvantage in retreating from commercialization is that it would be the third major shift in the institutional character of the U.S. industry in a decade. The industry has just begun to recover from the previous shifts--to the shuttle alone and then back to a mixed fleet. The process of consolidation and coordination required to create a national launch company could be expensive and chaotic. The transition from the current alignment of launch vehicles to a single family would impose costs not only on the launch sector, but also upon satellite producers.

Several other negative consequences could follow from the creation of a national launch company. The benefits of diversity, important to national security, would be lost, although as a practical matter many payloads even now face a choice between only two alternatives: the shuttle, or an expendable launch vehicle in the appropriate size class. The loss of the market's judgment as to the value of space launch capacity is another potential drawback to a national launch company. Such a company would have an institutional interest in undertaking new investments and creating capacity that might not be justified from either a public or a private perspective.

CHAPTER III

REMOTE SENSING

Until the mid-1980s, the use of satellites to collect information about objects on the ground was exclusively a public activity in the United States. The federal government developed, produced, and operated satellites that collected the raw data necessary for informational products that were mostly used for governmental purposes. A departure from this policy came in 1984, when the Congress decided to privatize the Landsat system. That system includes the satellites, ground stations, and processing equipment developed by the federal government to gather data about the land. The Land Remote Sensing Commercialization Act of 1984 began a 10-year experiment with the objective of transforming the Landsat system from a research project into the productive base for a new private industry.

Seven years into this experiment in space commercialization, its premise--that a new private industry can be created by the transfer of federal assets and with limited subsidies--is under challenge. While some progress has been made in privatizing Landsat, the prospects for a fully private system by the end of this decade are dim.

REMOTE SENSING DATA: THE CURRENT OUTLOOK AND POLICY OPTIONS

The Earth Observation Satellite Company (EOSAT), a private firm owned by Hughes Aircraft and General Electric, has undertaken the commercialization of the Landsat system. It operates the government-owned satellites Landsats 4 and 5, processes and markets the data they produce, and invests in ground facilities and, to a very limited extent, in a new satellite now being developed. In return, EOSAT receives the revenues from the sales of data and also receives federal funds to op-

TABLE 6. REVENUES OF MAJOR LAND REMOTE SENSING COMPANIES (In millions of dollars)

Year	EOSAT	SPOT Image	Total
1986	19	5	24
1987	21	10	31
1988	23	16	39
1989	25	22	47

SOURCE: Department of Commerce, *Space Business Indicators* (June 1990), pp. 16 and 35.

NOTE: EOSAT is the U.S. privately owned Earth Observation Satellite Company. SPOT Image is the company that markets the data of the French satellite, Systeme Probatorie d'Obervation de la Terra (SPOT).

erate the satellites and to cover more than 95 percent of the cost of building and launching a new satellite, Landsat 6. After the launch of the Landsat 6 in 1992, no additional support for EOSAT is planned.

Available evidence indicates that the large-scale systems currently used for remote sensing, such as the U.S. Landsat and its predominantly French European counterpart, Systeme Probatorie d'Observation de la Terra (SPOT), cannot generate sufficient revenues from data sales to cover their cost. Box 3 describes the products and technology of satellite remote sensing. The cost of building, launching, and operating two Landsat-type satellites during the 1990s could range from $0.75 billion to $1 billion, exclusive of the cost of capital and insurance that a private firm would have to bear. This amount translates into an average annual cost of $85 million to $110 million between 1991 and 1999. EOSAT revenues stood at $25 million in 1989, up from $19 million in 1986, as shown in Table 6. One recent analysis of the industry estimated that even a 20 percent annual rate of growth would not be enough to cover the full private-sector cost of remote sensing by the end of this decade.[1] SPOT's situation is roughly comparable.

1. Kodak Remote Sensing, *Study for an Advanced Civil Earth Remote Sensing System* (Department of Commerce, August 1988), p.11.

This pessimistic outlook for the prospects of land remote sensing as a private industry of the future--at least through the turn of the century--reflects a consensus of many recent studies. In 1988, the Department of Commerce, as part of a Landsat policy review, released a set of contractor studies.[2] One, by The Analytic Sciences Corporation (TASC), concluded: "Projected market revenues will not support a fully viable commercial civil Earth remote sensing system during the 1990's."[3] Another, by Kodak Remote Sensing, reached a similar conclusion: "The space segment cannot be commercialized during the present century, even under the most optimistic market projections."[4] EOSAT, in an independent study of its own presented to the Congress, was less direct: "This study finds that the special risk/return characteristics of an advanced satellite remote sensing system serving a wide variety of markets over the next eight to ten years precludes conventional private or multinational financing of the investment required for an advanced Landsat 7 system."[5] What is left of the vision of a fully commercial system of the Landsat or SPOT type according to the financial analysis included in the TASC study, is "a marginally profitable and financable system" if the government is willing to be cooperative and to implement "aggressive private sector risk reduction strategies."[6]

Currently, the total cost to society of producing land remote sensing data exceeds what the public and private buyers of the data are

2. This review produced three contractor studies to support the Department of Commerce's process of deciding what to do about Landsat. The three studies are: The Analytic Sciences Corporation (TASC), *A Study of an Advanced Civil Earth Remote Sensing System* (Department of Commerce, August 1988), hereafter the TASC study; Kodak Remote Sensing, *Study for an Advanced Civil Earth Remote Sensing System* (Department of Commerce, August 1988), hereafter the Kodak study; and The Egan Group, *Study for Advanced Civil Earth Remote Sensing System* (Department of Commerce, August 1988), hereafter the Egan study. EOSAT produced an independent study on the same issue: Earth Observation Satellite Company, *Landsat 7: A Comprehensive Study* (January 1989).

3. The Analytic Sciences Corporation (TASC), *A Study of an Advanced Civil Earth Remote Sensing System*, p.1-9.

4. Kodak Remote Sensing, *Study for an Advanced Civil Earth Remote Sensing System*, vol. 1, p. 6.

5. EOSAT, *Landsat 7: A Comprehensive Study*, p. 1.

6. The Analytic Sciences Corporation, *A Study of an Advanced Civil Earth Remote Sensing System*, pp. 4-16.

BOX 3
Remote Sensing Products and Technology

In its essentials the information provided by satellite remote sensing is simple. A photograph from space allows the object on the ground to be identified because the observer knows what it looks like. Similar to a visible light photograph, an infrared image of an agricultural area allows an observer to estimate yield because the reflective properties of a good crop or a bad crop are known. Remote sensing data can be converted into useful information in a variety of areas. In agriculture, satellite data can be used to identify crop types, acreage planted, and the health of specific crops, and to monitor soil moisture. The timber industry uses remote sensing data to discriminate among the types of timber, to assess timber quality, and to evaluate the damage caused by forest fires. The mineral and extractive industries have found satellite data useful in surveying large areas of land for topological signs of mineral and petroleum deposits. Land use and water resource applications of remote sensing information include mapping, regional and urban planning, commercial location, and monitoring of coastal areas and flood plains. Satellite data can also be used to monitor both air and water pollution. Finally, although commercial remote sensing is usually described as a civilian enterprise, the large sales of remote sensing data to the military indicate significant military applications.

<u>The Raw Data</u>

In its earliest use, remote sensing was synonymous with satellite photography. Aerial photography remains a substitute for some of these applications of satellite remote sensing data. Satellite data are sold to customers in their most basic form either as photographic images or in a digital computer-readable format on floppy disks or tapes. Data that are processed to this extent only, are referred to as unenhanced or raw data. The quantity unit of measurement for raw data is a scene that may be purchased as a whole or in parts. Scenes that provide greater detail are more expensive than less detailed scenes. Digital-format products are more expensive than photographic images but are potentially more valuable. The geographic size of a scene depends on the characteristics of the remote sensing system. Landsat covers an area of about 110 miles wide in a scene and Systeme Probatorie d'Observation de la Terra (SPOT) considerably less. SPOT is capable of providing more detailed scenes, however.

The sensors a satellite carries determine the information it gathers. A broad range of options are open across the electromagnetic spectrum from ultraviolet through visible light up to infrared frequencies. The choices made in this dimension, referred to as "spectral resolution," determine which applications and markets will find the data gathered useful. For example, construction, engineering, and mapping applications require only the visible light portions of the spectrum. Agricultural forecasters require infrared readings as well as visible light. Energy and mineral prospectors prefer even broader infrared coverage. The Landsat series of satellites has consistently expanded its spectral range. Currently, the thematic mapper sensor aboard Landsat 5, and to be carried on Landsat 6, offers the broadest spectral resolution commercially available with its capability to read seven different spectral bands stretching from visible light into the infrared frequencies.

The level of detail discernible in a remote sensing image defines a system's "spatial resolution." As with spectral resolution, different applications require different levels of spatial resolution. Engineering, construction, and intelligence community users prefer fine resolution, 10 meters by the current industry standard. For other applications, such as forest yield or crop forecasting, less fine resolution in the range of 30 meters to 80 meters is desired. While the most advanced military satellites reportedly can produce a visual image of an object only inches in diameter, SPOT's 10-meter resolution is the finest commercially available.[1] Coarser resolution of 250 meters to 500 meters is necessary for large-scale environmental surveys. Finer spectral resolution sensors capture a narrower area of territory, or swath, as a satellite passes over the ground. Thus, there is a trade-off between the size of the scene and spatial resolution.

Remote sensing products can also be defined in two time dimensions: the time its takes to acquire, process, and deliver new data to a customer, and the length of the historical record of usable data a system provides. The Landsat system orbiting the Earth's North and South Poles revisits the same location on the globe each 16 days. SPOT, while in a similar orbit, can provide limited coverage as frequently as every seven days because its sensors are able to take off-angle readings.[2] Some potential markets for remote sensing data, for example the media, require a turnaround time of hours or days. Currently, once an image is acquired, EOSAT's turnaround time is upward of a week. SPOT claims a slightly quicker turnaround. Public and private planners alike can use time series images of the same area. Landsat's time series goes back to the mid-1970s for its most basic images and to the late 1970s for its more sophisticated thematic mapper data.

Once an image has been captured, it is transmitted to a ground receiving station. Both the Landsat and SPOT systems have a primary ground station and an international network of receiving stations. All ground stations receive data obtained while the satellite is overhead, limited by the ability of the rapidly moving satellite to "see" the ground station as it passes from horizon to horizon. International receiving stations pay EOSAT and SPOT Image for the right to this data and resell it to foreign and domestic buyers. Primary ground stations receive additional data from a wider geographic area. SPOT Image employs an onboard storage recorder that captures data from around the world and transmits it to the primary station when the satellite is overhead. EOSAT uses a relay satellite to transmit data from areas beyond the sight of the primary ground station. Both the SPOT and Landsat systems collect data tapes captured by their international networks and maintain an archive of images from around the world.

Value-Added Services

The data produced by a remote sensing satellite are in many cases an input for subsequent processing and interpretation. The value-added sector improves the information quality of the raw data. At the simplest level, a value-added service is expert interpretation of a photographic image. As computational power has become readily available and less costly, value-added services increasingly involve developing and using software to refine and increase the value of satellite data. Value-added producers, of which there are a large number, have been able to charge their customers a price sufficient to cover the cost of acquiring and transforming the data, and to make an acceptable rate of return. The marketing activities of these firms could be a factor expanding the market for remote sensing data.

1. "Sensing the Earth from Space," Harvard Business School, N9-389-154 (1989), p. 3.

2. Off-angle sensor movements also permit stereoscopic images to be gathered, allowing a better reading of topology.

willing to pay for it. The market may fail to capture the full value of the data to society, for several reasons. First, the data produced by Landsat can be widely distributed at minimal cost beyond the immediate public or private purchaser and put to valuable use by others. Current prices fail to capture this value.

Second, a part of the social value of Landsat data may be inappropriately reflected in the revenues of private firms that buy remote sensing data and resell it. These firms, value-added producers as they are called, have sales two to four times greater than the sales of Landsat and SPOT data.[7] Regulations limiting the pricing and distribution policies of EOSAT or potential new suppliers of data may prevent the producers of data from charging prices and imposing terms of sale that would capture their share of the value of the data they produce. A similar case can be made about the international network of ground stations. Current law limits the annual fee EOSAT can charge these stations and prevents EOSAT from charging different stations different fees for the data they receive and subsequently resell.

Third, the value of Landsat data sold to public buyers may also not be fully reflected in the prices they pay for it. To begin with, the public goods to which Landsat data contributes are not well priced in the market--for example, better maps to support U.S. troops in the field, or the identification of the breeding areas of disease-carrying mosquitos. In addition, at the federal level, the agencies that find Landsat data most useful may not be paying its full value, hoping eventually to share the cost with other agencies. The unpaid-for value of Landsat data is covered by federal subsidies for current operations and in the larger appropriations necessary to build new satellites.

Policy toward privatizing remote sensing hinges around whether the federal government will fund new satellites. As Box 4 shows, uncertainty and shifts in circumstances characterized policy and funding for Landsat during the 1980s. Ending federal funding would mean that as Landsats 4 and 5 reached the end of their lives, EOSAT would be forced to stand or fall in the mid-1990s as the market

7. Kodak Remote Sensing, *Study for an Advanced Civil Earth Remote Sensing System*, p. 34. and The Analytic Sciences Corporation (TASC), *A Study of an Advanced Civil Remote Sensing System*, p. 2-47.

dictated. The option of ending federal support for the privatization of remote sensing is consistent with the belief that the value of this activity can be fully reflected in the market. Alternatively, a commitment to provide new public funding for remote sensing would imply a belief that the market currently undervalues the social worth of remote sensing data.

An option to encourage private investment in remote sensing activity if no additional funding for Landsat is provided would be to deregulate the market for remote sensing data by permitting a producer to charge different prices to different customers and to grant exclusive data rights to customers that are willing to pay. If private investors were to test the market under these circumstances, they would be likely to do so with satellite systems that are smaller, less expensive, and less capable than Landsat. The prospects of these "lightsats," however, have yet to be tested in the market.

In any renewed public commitment to finance remote sensing, the issues would be how to maximize the social benefits of the data obtained from remote sensing, and how to distribute these benefits. One option would be to publicly underwrite some or all of the capital costs while allowing private investors to operate the system and distribute the products. This option could be pursued in more than one way: for example, by continuing the current relationship with EOSAT and negotiating a federal contribution to a new satellite, or by auctioning off distribution rights to investors willing to share the cost of new satellites. A second option would be to return remote sensing to the public sector. A third option would be to conclude an agreement with other countries to create an international public institution that would coordinate the design, launching, and operation of remote sensing satellites. This approach might include a role for the private operation of satellites and distribution of data.

CONDITIONS OF SUPPLY

Several factors determine the conditions under which remote sensing data are currently supplied. One is that the average cost of producing

BOX 4
A History of Remote Sensing Policy

During the 1970s, the U.S. public sector developed technology for land remote sensing, operated the satellite systems, explored new uses for the data, and was the primary purchaser of data once uses were developed. The U.S. government pioneered the use of satellite images in agriculture, geology, forestry, planning land use, and mapping, among other applications.[1] As a part of its foreign policy the government encouraged the construction of foreign ground stations to receive satellite data, and through foreign aid programs, built ground receiving stations and promoted use of remote sensing data in the cause of economic development. Private petroleum and mineral producers were also among the earliest customers for remote sensing data. These companies paid fees for the data that covered no more than a modest fraction of the cost of operating remote sensing systems and none of its capital costs. The costs were substantial. Before 1984, the government spent $1.5 billion on Landsat, the U.S. civilian remote sensing system.[2]

The situation changed in 1984. The government decided to commercialize the Landsat system. The Land Remote Sensing Commercialization Act legislated this change and outlined a transition plan that included both operating and capital subsidies from the government to the future private owner/operator of the system. The law also opened the door for new private entry into satellite remote sensing and established the Department of Commerce as the agency responsible for developing a procedure to license new entry.[3]

The move to commercialization in the United States was not abrupt, but has proved to be difficult. During the Carter Administration, the government weighed options to commercialize or to privatize the Landsat system.[4] By the end of the Carter Administration, the favored option was privatization. A private entity would operate the system and distribute its products, but the federal government would maintain a financial role into the indefinite future. By 1983, responsibility for the Landsat system was transferred from the National Aeronautics and Space Administration to the National Oceanic and Atmospheric Administration, reflecting a change in the public policy perception of the system from a research and experimental system to an operating system.

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1. Stanley A. Morain and Pitt G. Thome, *Situation Analysis: A NASA Perspective on Commercial Earth Observation* (Technology Applications Center, Albuquerque, and Center for Space and Advanced Technology, Arlington), January 1989, pp. 16-22, provides a review of NASA's efforts to promote the use of satellite data during the 1970s and first half of the 1980s.

2. "Sensing the Earth from Space," Harvard Business School, N9-389,154, 1989.

3. Office of Technology Assessment, *International Cooperation and Competition in Civilian Space Activity* (July 1985), p. 289.

4. Department of Commerce, *Planning for a Civil Operational Land Remote Sensing Satellite System: A Discussion of Issues and Options* (June 20, 1980), presents the results of the consideration of Landsat options initiated during the Carter Administration.

By 1985, the Earth Observation Satellite Company (EOSAT) had won the competition to commercialize Landsat. EOSAT was to assume responsibility for marketing, pricing, and distributing Landsat data, operating the government's two satellites--Landsats 4 and 5--and building two new Landsat satellites to be launched in 1988 and 1992. Revenues from data sales beginning in 1985 would flow to EOSAT rather than the government. The government was to pay for operating Landsats 4 and 5 (which were expected to fail in one or two years), for two new satellites, and for their launch on the space shuttle. A resource commitment of $295 million was anticipated.[5] This commitment was less than the $500 million figure understood to be available by most of the bidders at the time of their submissions and led Eastman Kodak, EOSAT's final competitor, to withdraw from the bidding.[6]

A conspiracy of events has resulted in changes in the major aspects of the original agreement. Disagreements among the line agencies of the federal government, between the Office of Management and Budget (OMB) and federal agencies and between the Administration and the Congress led to an uncertain budget outlook for the construction funding of the new satellites. In 1987, this situation became acute, and EOSAT halted production of Landsat 6. The Challenger accident resulted in a change in launch vehicles from the shuttle to an expendable launch vehicle, and a change in the design of the satellite. The corporate ownership of EOSAT changed when General Motors acquired Hughes and General Electric acquired RCA. Finally, both the Landsat 4 and 5 satellites exceeded their expected lives, shortening the gap between the end of their useful lives and the operation of Landsat 6, but creating the question of whether EOSAT or the federal government will pay for their continued operation.

Currently, a 1988 agreement between EOSAT and the federal government is in place. One new satellite will be built instead of two with federal support valued at $250 million, $210 million for satellite construction and a government-provided launch valued at $40 million. In addition, continuing federal support has been provided to EOSAT for the operation of Landsats 4 and 5, roughly $20 million during 1990. For its part, EOSAT continues to invest in ground processing equipment and marketing, and most notably will invest $30 million in the construction of Landsat 6 to cover its current estimated cost of $240 million.[7]

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5. Karl A. Roher and Marcia S. Smith, *The Future of the Land Remote Sensing Satellite System (Landsat)*, CRS Report for Congress (April 1989), p. 2.

6. James V. Taranik, "Landsat, Privatization, Commercialization, and the Public Good," *Space Commerce*, vol. 1 (1990), p. 75.

7. Karl A. Roher and Marcia S. Smith, *The Future of the Land Remote Sensing Satellite System (Landsat)*, pp. 1-5 and Appendix I, provides a summary of the changes in the Landsat commercialization agreement and the federal support necessary to implement the agreement.

data declines as more data are produced. Declining costs are typical of public utilities, where a number of regulatory mechanisms have been developed to protect the public interest.[8] Box 5 describes the problem of the decreasing-cost industry.

A second factor is the way in which the market for raw data is regulated. The Land Remote Sensing Commercialization Act limits the flexibility of EOSAT and other potential U.S. entrants in setting prices and granting access to data. These regulations force providers of raw data to make data available to all customers on the same terms, under what is called the nondiscrimination principle. The benefit to the United States of maintaining the principle of nondiscrimination is the goodwill of nations over which remote sensing satellites fly. The cost is the limitation placed on the possibility of successful private investment.

Public investment in remote sensing systems is a last major supply-side factor to be taken account of. Competition in the current market for land remote sensing data is essentially between two mixed enterprises, this country's EOSAT and Europe's SPOT, both of them receiving public subsidies. In the United States, public policy and investments also define the domain of remote sensing activity that is treated as public and that which is considered private. For example, under current policy land remote sensing is to become a private activity, while remote sensing activity to gather weather data is to remain public. Planned increases in public investment in remote sensing systems for the atmosphere and oceans will make available a large volume of new remote sensing data for processing and distribution toward the end of the decade. Significant savings may be possible if the private sector proves to be a more cost-effective distributor of this information than the public sector.

8. Alfred E. Kahn, *The Economics of Regulation: Principles and Institutions* (New York: John Wiley and Sons, Inc., 1970), vol. 1, chap. 5, provides a discussion of the cost characteristics of a declining-cost industry and its implications for pricing and economic efficiency.

BOX 5
The Decreasing-Cost Industry

In most industries, producers operate with constant or increasing costs. Market forces establish a price that leads the individual producer to supply just enough of a product so that the additional, or marginal, cost of the last unit produced is equal to the market price. Typically, the cost of producing additional units rises as more are produced, eventually causing the average cost of all units to rise. In an ideal competitive industry, an individual firm produces at the level where the cost of the last unit produced is equal not only to the market price but also to the average cost of all the units produced. This ensures that all costs are covered by revenues and that society's resources are efficiently used.

In a decreasing-cost industry, however, high fixed costs mean that the average cost of production keeps on declining as more units are produced, for all quantities that consumers are likely to demand. Consequently, a single producer can supply the entire market at the lowest cost to society. For this reason, decreasing-cost industries are sometimes referred to as natural monopolies. In the decreasing-cost industry, market prices, marginal costs, and average costs are never equal.

Decreasing-cost industries are usually regulated or subsidized, thus allowing for a variety of solutions to their pricing dilemma. Waterways and dams often charge a low or even a zero price to assure wide use of the product, with taxes making up the difference between costs and revenues. Electric utilities price their power under a variety of regulatory strategies, often charging different rates to different customers for the same product. Through such price discrimination, a second-best solution to the decreasing-cost industry is achieved. The full cost of production is recovered from those customers willing to pay the highest prices. Wide social benefits are secured by charging other customers less, even as little as the marginal cost of production. The logic of economics thus suggests that price discrimination is an effective solution in the production of raw data by remote sensing. The logic of international relations, however, argues against price discrimination. Thus, the Land Remote Sensing Act requires that all parties have access to data on equal terms.

Structure, Scale, and Cost

The structure of the industry producing land remote sensing information includes two levels--that of raw data production and that of value-added production. The two main producers of raw data--EOSAT and SPOT Image--each has a primary ground station and processing facility. In addition, each has an affiliated network of international ground stations that are publicly owned by the countries in which they are located, and pay annual access fees or royalties or both on sales of data to the raw data producer in exchange for receiving data. On the other level, that of value-added production, are many firms that buy data from EOSAT and SPOT, improve its information quality, and resell it to final users.

Raw Data Producers. The cost of current remote sensing activities is dominated by the cost of the "space segment" necessary to produce raw data--that is, satellites and their launch and ground support facilities. Landsat and SPOT are both large-scale systems that rely on large satellites carrying several different types of sensors. Landsat satellites are designed to last five years, but SPOT satellites for only three. Landsat 6 will cost $240 million to build and an additional $40 million to launch.[9] Current estimates of the cost of SPOT satellites are comparable. The total cost of ground facilities and four SPOT satellites, two that are already built and two planned for the 1990s, is $1.2 billion exclusive of launch costs.[10]

Unlike Landsat, SPOT had a private and commercial aspect from its inception. SPOT Image, a mixed enterprise of which the French government owns almost half, was established to operate the system and to market and distribute its product on a commercial basis. Roughly a third of SPOT Image is owned by aerospace firms that build the SPOT satellites and related systems. While initially it was hoped that data sales from the first SPOT satellite would build a market sufficiently strong to pay for subsequent satellites, the $22 million of

9. Earth Observation Satellite Company, *Landsat 7: a Comprehensive Study*, p. xx, provided the Congress with a broad range of options for new remote sensing satellites, from $160 million (1988 dollars) to $800 million (1988 dollars).

10. "SPOT's Subsidized Success Story," *Space Markets*, 2/90, p. 102.

sales in 1989 only approached the level necessary to cover operating costs. By tailoring its product differently from that of Landsat (SPOT images cover less area in fewer spectral bands, but in more detail than EOSAT), SPOT has acquired customers that find the unique aspects of its data useful. In addition, SPOT has tapped the market for remote sensing data among those customers who will buy virtually any product on the market--for example, military and national security buyers. Some users have been able to enhance the value of Landsat data by merging it with SPOT data. These relationships among products and customers, and the youth of the industry in general, have led some observers to suggest that SPOT and Landsat products are more complementary than competitive.

Currently, operating systems on the scale of Landsat and SPOT cannot provide data at a cost that the market can cover. Market demand is so weak, relative to the scale of current systems, that even a producer with a world monopoly would have difficulty charging a price sufficiently high to cover the cost of production. The Kodak study illustrates this point in a projection showing that even if a single producer of land remote sensing data captured the entire market and grew at 20 percent annually during the 1990s, it could not produce sufficient revenues to cover the cost of the space segment until 2000.[11]

This characteristic of the current market suggests that a single land remote sensing system, as envisioned in the international consortium option, could be more efficient than two competing private systems by producing roughly the same data currently available with one system. The argument holds only so long as market growth and technology allow it to do so. Lower-cost technology could permit competing systems to cover their cost in the market. Dramatic growth in demand could have the same effect. Some analysts have argued that exactly such circumstances have rendered the regulated monopoly in international satellite communications, Intelsat, obsolete.[12] Public institutions that in the short run may appear efficient could in the long

11. Kodak Remote Sensing, *Study for an Advanced Civil Earth Remote Sensing System*, p. 11.

12. Robert W. Hahn and Randall S. Kroszner, "Lost in Space: U.S. International Communications Policy," *Regulation* (Summer 1990), pp. 57-65.

run become obstacles to technical change and the provision of services desired by consumers.

An alternative to the current approach to producing raw data would be to allow public and private sensors to share the same satellite "bus"--that is, the generic satellite including maneuvering engines, onboard power supply, and communication equipment. By allowing such sharing, it would permit large-scale operation at a lower cost. Private sensors could be placed in rented space aboard a public satellite, or a public sensor could rent space on a private satellite. Either arrangement could provide private remote sensing with economies of scope--in this case, the saving gained from sharing the satellite with sensors producing other types of data. Such arrangements would, however, require compromises in spectral coverage and in the time it takes to acquire a desired image.[13]

Small single-sensor satellites would also reduce costs of producing data, although the studies commissioned by the Commerce Department did not show that such a venture would be profitable.[14] The cost of such a system, variously referred to as "lightsat" or "cheapsat," has been estimated at $15 million to $50 million plus launch costs of $5 million to $15 million.[15] The lower costs would be associated with lesser capabilities, and hence with a system having less revenue-generating potential. Smaller firms are currently developing systems of this type, but their technology is unlikely to be tested in the marketplace as long as publicly supported competitors remain in operation. Ending public support for Landsat would thus provide a more open field for smaller satellites.

Operating Costs. Once a satellite is in orbit, the annual additional cost of producing remote sensing raw data with a Landsat or SPOT system is currently around $20 million. These costs include operating the

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13. The Analytic Sciences Corporation (TASC), *A Study of an Advanced Civil Earth Remote Sensing System*, p. 3-19.

14. The Analytic Sciences Corporation (TASC), *A Study of an Advanced Civil Earth Remote Sensing System*, p. 4-10 and pp. 3-14, 3-15, and Kodak Remote Sensing, *Study for an Advanced Civil Earth Remote Sensing System*, vol. I, p. 23.

15. The Analytic Sciences Corporation (TASC), *A Study of an Advanced Civil Earth Remote Sensing System*, pp. 3-14 to 3-16.

satellite and programming its sensors to capture specific images, processing the data into digital tape or image form, and marketing and distributing these products. For most products, these costs are probably constant or increase as more data are demanded. For all policy options, these costs provide a benchmark for efficient pricing. For policy options that involve a private operator, these are the minimum costs that must be covered in the marketplace.

The claim that a private investor is better able to lower the cost of ground processing than a public operator is a key point in the case for continued private involvement in land remote sensing, even if the market cannot support a fully private system. The claim is based largely on the conceptual argument that the profit motive ensures better control of costs than do administrative directives.

EOSAT has probably lowered the ground operations cost of producing land remote sensing information, although the evidence is inconclusive and difficult to evaluate. EOSAT claims that the federal budgetary resources necessary to operate Landsat have declined as a consequence of commercialization. By EOSAT's estimate, federal spending to operate the Landsat systems has fallen from $36 million in 1985--the last year of federal operation--to below $20 million in 1990.[16] During 1985, however, data sales and international ground station fees provided offsetting revenues of over $15 million. Thus, the net position of the government remains virtually unchanged under private operation.

EOSAT has achieved a lower unit cost for the ground operations of producing data, however. The volume of digital products, which are more difficult to produce, almost doubled between 1985 and 1989, more than offsetting a large drop in photographic images, which are less

16. Statement by Pete Norris, Executive Vice President, Earth Observation Satellite Company, before the Subcommittee on International Scientific Cooperation and the Subcommittee on Natural Resources, Agriculture, Research and Environment of the House Committee on Science, Space and Technology, *Images of the Earth From Space: Innovative Applications, Advanced Technologies, and New Markets*, 101:2 (February 15, 1990), p. 48.

difficult to produce.[17] Over the same period of time, revenues have increased from about $15 million to $25 million, with the price of products held roughly constant. EOSAT claims that costs will be further reduced in the future as the 1970s-vintage processing equipment, inherited by EOSAT from the government, is replaced with new equipment.[18]

If indeed the private sector can operate satellites and distribute their product more cheaply than the public sector, the difference may be accounted for by other factors than inefficiency in the public sector. Cost control in the public sector may take second place to other objectives--for example, basic research and development. In the case of Landsat, the public agencies operating the system did so under mandates unlikely to allow for cost reduction. The National Aeronautics and Space Administration was running a research program. The National Oceanic and Atmospheric Administration was the caretaker of a system in transition. Consequently, the comparison of EOSAT with its predecessor does not show conclusively whether some future government-operated system with the explicit mandate to control costs could perform as well as EOSAT.

Value-Added Production. The cost of the value-added activities performed by firms that buy data from EOSAT and SPOT in order to resell it to final users depends on the amount of processing they do. The Kodak study of the remote sensing industry examined the computer equipment necessary for many value-added activities; it identified a range of systems from a personal computer-based system costing $25,000 to one based on a mainframe computer costing as much as $1 million.[19] These costs, unlike those of the space segment, do not represent a barrier to entering the industry, which has seen a proliferation of value-added firms during the 1980s. Value-added producers are expected to benefit from technical change in the computer industry

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17. U.S. Geological Survey, EROS Data Center, "Summary of Worldwide Landsat Data Sales 1989," prepared for Landsat Data Distribution and Marketing Working Group, Canberra, Australia, May 21, 1990, pp. 1 and 3.

18. EOSAT, communication with the author, October 26, 1990.

19. Kodak Remote Sensing, *Study for an Advanced Civil Earth Remote Sensing System*, vol. 3, pp. 2-18 to 2-20.

that will lower the cost of current applications and create new applications. The increase in value-added sales in recent years implies a growing demand for raw data in the future.

Not enough information about value-added producers is available to determine whether allowing raw data producers to pursue different pricing strategies could allow them to capture a part of the revenues currently held by value-added producers. The TASC study suggested this possibility. The competitive structure of the value-added sector, with its many firms, suggests that cost savings in raw data production will ultimately be passed along to final consumers. Some value-added activities, however, involve special expertise or possessing mathematical formulas that permit extracting specific information from a set of digital data. Firms with these advantages might be able to charge relatively high fees for their products, thus capturing high profits.

Regulation and Competitive Behavior: EOSAT and SPOT Image

By law the Landsat system operates under the condition of "open skies" and nondiscriminatory access to remote sensing data.[20] The open skies principle declares outer space to be an international zone open for all to use. The nondiscrimination principle holds that all parties should have access to raw data on the same terms. The Land Remote Sensing Commercialization Act requires EOSAT and any other U.S. entrant to adhere to this principle, effectively prohibiting price discrimination. Underlying the U.S. adherence to the nondiscrimination principle are a desire to be fair to countries over whose territories U.S. satellites gather information, and the perception that there are foreign policy benefits in allowing other countries equal access to U.S.-developed systems. The issue of fairness in land remote sensing arises because only technically advanced countries are able to build and launch satellites, while the information they gather about

20. President Eisenhower put forward the earliest formulation of the open skies policy. For discussion, see Walter A. McDougall, *...the Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985), pp.127-128. The policy is formalized in the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies. See Office of Technology Assessment, *Commercial Newsgathering From Space* (May 1987), p.49.

all countries could be of commercial advantage to anyone possessing it, particularly as concerns the natural resources sector.

EOSAT might have a better chance of closing the gap between revenues and cost if it was permitted to charge different customers different prices for the same information or service. For example, clients willing to pay higher prices could be provided data on an exclusive basis. EOSAT is also restricted from practicing price discrimination among its international ground stations. In this case, while EOSAT's income increases with greater sales of data because it receives a royalty on sales to those ground stations, it has no way to capture a larger share of the returns from those stations' sales of raw data to others.

While the nondiscrimination principle does not explicitly prohibit EOSAT from moving downstream into value-added services and products, that principle is an element of the environment shaping EOSAT's strategy. Success in value-added markets could evoke suspicion that EOSAT's value-added operation was being given discriminatory access to raw data. Instead, EOSAT relies on firms in the value-added sector to expand the market for raw data through their effort to sell value-added products and services. In this context, EOSAT contends that a move into the value-added sector would represent competition with its own customers. The TASC study of the remote sensing market in the 1990s specifically addressed the question of whether or not a move into the value-added market could allow a large-scale remote sensing data producer to become commercially successful.[21] Its conclusion was that a Landsat-scale producer would still be unable to increase revenues enough to cover the full cost of raw data production.

SPOT Image's choice of strategy reflects a different view. Its sales of value-added products--five types of maps--could by one estimate generate as much as 30 percent of its expected $25 million revenues in 1990.[22] In addition, SPOT will reprogram its satellite images for customers who are willing to pay. At one time, the U.S. government of-

21. The Analytic Sciences Corporation (TASC), *A Study of an Advanced Civil Earth Remote Sensing System*, pp. 1-10.

22. *Space News* (June 11-June 18, 1990), p. 23.

fered similar Landsat services and applied special acquisition charges. EOSAT, however, while willing to acquire images requested by its customers, has discontinued charging the additional fees. SPOT Image drew as much as 10 percent of its 1989 revenues from charges for priority, according to one account.[23] Once SPOT produces an image, however, it becomes available to all buyers on standard terms, consistent with SPOT's adherence to a policy of open skies and equal access. Unlike EOSAT, SPOT also has flexibility in the prices it charges its international receiving stations. A minimum charge of $800,000 is required, but annual fees of as high as $2 million have been reported.

Public Investment in Remote Sensing

Most remote sensing activities under U.S. sponsorship are conducted by the public sector, including military, weather forecasting, and scientific research activities.[24] Proponents of commercialization argue that the present policy of restricting the scope of private activities to land remote sensing greatly decreases the prospects of successful private investment. From this point of view, the problem with remote sensing commercialization is that its market is artificially limited, and that a private system could succeed only if the government were to retire from the playing field. The Comsat corporation at one point proposed privatizing both the land remote and the weather satellites.[25] The law commercializing Landsat, however, explicitly prohibits commercializing the weather satellites.

In the future, the relation between public and private remote sensing is likely to grow more complicated. Foreign governments plan major new systems that will produce data overlapping that of EOSAT and SPOT. International concern with global climate change is leading to new investment in very large and capable remote sensing satel-

23. "SPOT's Subsidized Success Story," *Space Markets*, 2/90, p. 102.

24. Office of Technology Assessment, *International Cooperation and Competition in Civilian Space Activities* (July 1985), chap. 7, provides a broad view and description of remote sensing applications and technologies.

25. James V. Taranik, "Landsat Privatization, Commercialization, and the Public Good," *Space Commerce*, vol. 1 (1990), p. 75.

lites that are likely to begin producing data in the late 1990s. These developments present opportunities and challenges to private investment in land remote sensing.

Japan, Canada, India, and the Soviet Union will, by the mid-1990s, all have remote sensing systems that produce data potentially competitive with Landsat and SPOT data in certain segments of the information market. However, just as SPOT and Landsat data are to some extent complementary, there is complementarity between the data produced by all other public systems and SPOT and EOSAT. The availability of more data generally creates more interest in its applications. The increased data allow different streams of information to be combined in value-added products. For example. some maps produced with satellite data combine data from SPOT and Landsat. International research into global climate change will potentially increase the market for remote sensing data, create more opportunities to combine land sensors with other types of sensors, and generate large flows of new data that private investors could help to distribute. The commercialization policy of the mid-1980s sought to open only one type of data to the private sector. The proliferation of data types in the future enhances the prospect of commercializing a part of remote sensing activity--satellite operation and/or data processing and distribution--among all types of data.

CONDITIONS OF DEMAND

Experience to date with the demand for remote sensing data suggests that full commercialization will be difficult, but perhaps not impossible. It also suggests that policy options in which the government would provide additional funds for satellite construction would be a remedy for the declining cost problem. The historical evidence cannot, however, fully answer the fundamental question of whether or not Landsat's social value is enough to justify its cost.

Market Size and Composition

The estimated total revenues of the providers of raw data, SPOT Image and EOSAT, allow an approximation of the value of sales of worldwide remote sensing raw data since 1973 (see Table 7). The increase in the value of Landsat data sales in the late 1970s and early 1980s, from an

TABLE 7. REVENUES OF RAW DATA PROVIDERS, INCLUDING ACCESS FEES FOR FOREIGN GROUND STATIONS AND SALES OF RAW DATA (In millions of dollars)

Years	Revenues
1973	0.2
1974	0.5
1975	0.9
1976	2.2
1977	2.3
1978	2.8
1979	3.4
1980	3.8
1981	4.5
1982	7.6
1983	12.3
1984	14.5
1985	16.9
1986	21.0
1987	31.0
1988	39.0
1989	47.0

SOURCES: Congressional Budget Office; Office of Technology Assessment; The Analytic Sciences Corporation; National Oceanic and Atmospheric Administration; Department of Commerce.

NOTE: For 1973-1982, total revenues are the sum of direct data sales as reported in Office of Technology Assessment, *International Cooperation and Competition in Civilian Space Activity* (July 1985), pp. 298-299, and foreign ground station access fees from various sources. Before 1976 no access fees were charged. For 1976-1978 CBO estimated access fees based on the number of commissioned foreign ground stations and the annual access fee of $200,000. For 1979-1982, foreign ground station access fees are as presented in The Analytic Sciences Corporation (TASC), *A Study of an Advanced Civil Earth Remote Sensing System* (April 1988), p. 2-40. For 1983-1985, total revenues are provided by the National Oceanic and Atmospheric Administration. For 1986-1990, total revenues are the sum of EOSAT and SPOT Image revenues as presented in Department of Commerce, *Space Business Indicators* (June 1990), pp. 16 and 35.

annual level of $1.5 million in 1977 to more than $6.5 million in 1982, was a consequence of the introduction of digital products and also reflected the growing number of international ground stations--which increased from only three in 1975 to ten in 1981.[26] In 1982, an increase in annual access fees for international ground stations from $200,000 to $600,000 also contributed to increased revenues. The large jump in revenues occurring in 1983 was caused by a major price increase for all products. Beginning in 1986, SPOT sales added to the total sales of raw data providers. The current political situation in the Middle East is reportedly working to increase the sales of both EOSAT and SPOT.[27]

In 1987, sales to public and private buyers in the United States accounted for half of the combined data sales of the two companies; United States and European sales accounted for over 80 percent. These figures, however, exclude the sales of international ground stations and accordingly overstate the U.S. and European shares. The Commerce Department reports that foreign sales, particularly in Asia, are the most rapidly growing part of Landsat's market, increasing by almost 50 percent in 1989.[28]

The Kodak study broke down the 1988 U.S. market for raw data by major government agency and private-sector buyer, as shown in Table 8. The major customers for civil remote sensing products in 1988 were the extractive industries and the Defense Department, each accounting for about a quarter of the domestic market. The study indicated that the distribution of the private-sector purchasers in the world market is similar to that in the U.S. market. The similarity in the distribution by activities of domestic and international value-added producers buying raw data from EOSAT supports the Kodak conclusion (see Table 9).

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26. U.S. Geological Survey, EROS Data Center, "A Summary of Worldwide Landsat Data Sales," September 1985, p. 12.

27. "EOSAT Sees High Demand for Gulf Images," *Space News* (September 24-30, 1990), p. 3.

28. Department of Commerce, *Space Business Indicators* (June 1990), p. iv.

TABLE 8. SALES OF RAW DATA FROM LAND REMOTE SENSING IN U.S. MARKETS, 1988

Market	Sales	
	Millions of Dollars	Percent
Private Sector		
Extraction	2.7	26
Mapping	0.4	4
Forestry	0.4	4
Agriculture	0.2	2
Engineering	0.2	2
Other	0.4	4
Public Sector		
Department of Defense	2.6	25
Department of Agriculture	1.7	17
Agency for International Development	0.4	4
Department of the Interior	0.5	5
State and local governments	0.4	3
Academic	0.4	4
Nonprofit Organizations	0.1	1
Total	10.2	100

SOURCE: Kodak Remote Sensing, *Study for an Advanced Civil Remote Sensing System* (Department of Commerce, August 1988), vol. 2, pp. 1-11.

During the 1990s, EOSAT's revenues are projected to range between $30 million and $60 million annually, according to projections from EOSAT and the TASC and Kodak studies.[29] The forces driving the future remote sensing market are improvements in sensor coverage and in products, with the value-added sector accounting for an influx of new customers. A continued demand for EOSAT products may depend on an assurance that Landsat will continue, since customers may not be ready to make the investment necessary to use data unless they are reasonably certain of its future supply.

29. *EOSAT, Landsat 7: A Comprehensive Study*, p. 15; Kodak Remote Sensing, *Study for an Advanced Civil Earth Remote Sensing System*, p. 12; and The Analytic Sciences Corporation (TASC), *A Study of an Advanced Civil Earth Remote Sensing System*, p. 2-42.

TABLE 9. SERVICES PROVIDED BY DOMESTIC AND INTERNATIONAL VALUE-ADDED FIRMS PURCHASING DATA FROM EOSAT
(In percentages of all firms purchasing data)

Service	Domestic[a]	International[a]
Petroleum and Mineral Exploration	56	52
Civil Engineering and Land Use	73	65
Agricultural Assessment	59	54
Forestry	64	53
Coastal Studies	51	46
Oceanography	37	33
Hydrology	59	51
Engineering	33	40
Cartography	53	55
Media	19	11

SOURCE: Congressional Budget Office from Earth Observation Satellite Company (EOSAT).

a. Based on a total of 70 firms.

b. Based on a total of 209 foreign firms.

Two recent developments indicate that the government is likely to remain a prominent customer for land remote sensing data. First, in 1990 the U.S. Global Change Research Program was initiated. During the 1990s, it will require considerable amounts of Landsat and SPOT data in order to address questions about ecological systems and their dynamics.[30] A second source of public demand not fully reflected in the market projections above comes from recent U.S. military involvement in the Middle East. While the reported record sales for EOSAT in August 1990 probably represent only a temporary increase in demand, they raise the question of whether the full social value of Landsat data is reflected in the prices paid for the data. It is difficult to assign a value to data that enable more accurate maps to be made, possibly saving lives in time of war.[31]

30. National Research Council, *The U.S. Global Change Research Program: An Assessment of FY 1991 Plans* (Washington, D.C.: National Academy Press, 1990), p. 78.

31. "EOSAT Sees High Demand for Gulf Images," *Space News* (September 24-30, 1990), p. 3.

Market Characteristics: Historical Evidence

The Landsat experience demonstrates that the market for raw data resembles the markets for other goods in that the quantity of data demanded will increase if prices are reduced and decrease if prices are increased. For example, the announcement in 1981, 1983, and 1985 that the prices of digital products were going to be increased led to roughly a doubling in the quantity demanded of these products in the months preceding the increases, and to a drop in sales to very low levels immediately following the increases.[32]

These aggregate sales figures conceal differences in the responses of buyers in different segments of the market. In general, buyers in the public sector were less responsive to price increases than buyers in the private sector. For example, when the price of Landsat products tripled in 1983, the value of government purchases increased more than fivefold, while the value of private purchases fell by a third.[33] That the private sector is more sensitive to price changes means that price increases will not serve to increase revenues sufficiently to cover costs. Also, the greater willingness of the public sector to pay for data indicates that price discrimination offers a solution to the problem of declining costs. Under that remedy, the producer covers costs by charging more willing buyers a higher price and less willing buyers a lower price--as low as the additional cost of producing the last unit of output. When all consumers pay the same price, some will benefit because they would have been willing to pay more. In a declining-cost industry, price discrimination allows the producer to cover costs by capturing this difference. While EOSAT is not allowed to discriminate in its price setting, the federal subsidies it receives, when added to the prices it receives for data, approximate price discrimination, with the federal customer paying a higher price and the private customer a lower price.

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32. U.S. Geological Survey, EROS Data Center, *Annual Report of Landsat Sales for Fiscal Year 1986* (1987), p. 28.

33. Office of Technology Assessment, *International Cooperation and Competition in Civilian Space Activities* (July 1985), p. 298.

The experience with Landsat and SPOT indicates that the introduction of new or improved products can increase market demand. For example, from 1979 through 1984 the sales of new digital products increased each year, climbing from $750 thousand to $3.3 million. The point is reinforced by the jump in digital product sales following the introduction in 1984 of the new thematic mapper data.[34] The ability of SPOT to penetrate the U.S. market so rapidly also illustrates the appetite of some current buyers for any and all data, and the expansion of the market likely to follow the introduction of new data in any form.

Finally, the history of the market for remote sensing data, with the recent entry of SPOT, demonstrates that supply creates demand--at least in the public sector where the government is both producer and consumer. This point is illustrated by the increase in European purchases of raw data that accompanied the entry of SPOT into the market. In 1984, the European sales of the Landsat ground station were just over $1 million, while by 1987, after SPOT's first full year of operation, the data sales of SPOT by itself were almost five times greater.[35] Europe having a system of its own, supported by direct capital subsidies, must explain a large part of this increase. The presence of government on both the supply and demand sides of the market suggests that when new public systems enter the arena sales will increase, but that these sales will be proportionately larger in new countries entering the market as governments seek to support their own national systems.

POLICY OPTIONS

What roles should government and private investors play in the area of land remote sensing? Before addressing this question, it is necessary to decide whether the government ought to fund new Landsat satellites. That decision in turn depends on the answer to another question: since the data obtained by Landsat cost more to produce than EOSAT

34. U.S. Geological Survey, EROS Data Center, *Annual Report of Landsat Sales for Fiscal Year 1986*, p. 27.

35. U.S. Geological Survey, EROS Data Center, *A Summary of Worldwide Landsat Data Sales* (1985), p. 6, and Euroconsult, *World Space Industry Survey: Ten Year Outlook 1988 Edition* (Paris, 1988), p. 315.

can sell them for in the market, do the data have sufficient social value to justify a subsidy of Landsat? If the answer to this question is negative, and no additional funding is provided for Landsat satellites, then the issue becomes whether the government has any role at all other than as a purchaser of raw data. If not, an option would be to deregulate the industry--by permitting the private-sector producers of raw data to provide their services on an exclusive, discriminatory basis.

If, alternatively, the benefits of Landsat are seen to exceed its cost, and the Congress decides to continue public support, the issue of private investment hinges on whether a private provider is best able to deliver to society the benefits of land remote sensing. If so, a private role is possible under a variety of circumstances: the current arrangement in which EOSAT negotiates capital contributions with the government, an open auction of distribution rights among private firms, or participation by private investors in an international consortium.

End Federal Support for Landsat?

The major uncertainty in ending federal support for Landsat is whether EOSAT, left to itself, could go forward with a new satellite in the mid-1990s. The consensus is that it could not. Nevertheless, steps could be taken to make investing in a new satellite easier for EOSAT or for new entrants from the private sector.

The government could encourage producers of raw data in several ways. It could choose to abandon the principle of nondiscrimination by allowing producers to offer exclusive rights to data and to charge their customers higher prices for those rights. Exclusivity could be limited in time, so as to permit eventual full scientific use of all data. Equal access could be maintained by requiring an open auction procedure for those parties interested in exclusive rights. EOSAT's revenues could also be increased by permitting it to adopt SPOT Image's policy of negotiated annual access fees for international receiving stations.

A second step would be to include weather satellites in the area of commercialization, thus allowing private producers to offer a broader array of revenue-generating products. Economies of scope and scale would result. The costs of operating satellites could also be lowered if common platforms could be used for some weather and land remote sensing operations. The scope of private activities could also be broadened by permitting private producers to bid for the commercial rights to distribute the raw data expected to be produced by the Earth Observation System sometime in the late 1990s.

The weight of available evidence suggests, however, that commercial providers operating on the Landsat scale are unlikely to be successful, at least in the next decade. Without additional federal funds to build satellites beyond Landsat 6, EOSAT could fail, leaving the federal government the task of establishing U.S. policy without an operating Landsat system.

The major advantage of ending federal support for Landsat would be the savings to the federal budget from not buying new satellites--ranging from $0.5 billion to $1.4 billion through the 1990s. The cost to the public sector of ending federal support would be the loss of the data currently purchased and used for various purposes, among them national security. A part of this gap could be closed by substitutes--aerial photography, SPOT data, and perhaps eventually data from new private sources. Private buyers would have the same alternative sources of data open to them, but could suffer financially. Value-added firms that have developed products requiring Landsat would suffer the most. However, since the decision not to support new satellites would be made far in advance of the actual loss of data, all buyers--both public and private--would have adequate time to adjust.

Maintaining an environment conducive to new entrants--likely of the lightsat scale--would be easier if Landsat were out of the picture, since parts of the market it formerly occupied would be open. Currently, the U.S. government is supporting the development of lightsat technology that may have commercial applications in remote sensing. More aggressive support--free launches, for example--would not be consistent, however, with a policy of ending federal subsidies. The most important posture of the federal government toward new entrants, with or without Landsat, would be as a customer.

Commit to Long-Term Public Support

The federal government could choose to support civilian land remote sensing in a variety of ways. Among the options most discussed are three:

- Emphasizing private investment in the marketing and distribution of Landsat data, with the objective of providing currently available data at the lowest cost to the government. EOSAT, or a different firm, would conduct these activities on a profit-making basis. The capital cost of the system could be shared between the public sector and the private sector, with the private contribution determined by negotiation with EOSAT, as occurred in 1987, or by an auction open to all potential system operators. A federal agency would oversee the process;

- A return to the pre-1984 arrangement, with a remote sensing system financed and operated by the government; or

- Creation of an international consortium. This option would require SPOT, Landsat, and other land remote sensing systems to merge their physical assets and data streams. Private investors could operate the combined system and distribute its product.

Each of these options would require new spending to support the space segment of civilian remote sensing systems during the 1990s.

Costs of the Options

The costs of the options through the rest of the decade would differ in several dimensions. The option to maintain a private operator of the Landsat system would reduce satellite costs for two reasons: first, because the private operator of the system would presumably carry as much as a third of the cost of new satellites; and second, because the new satellites would be duplicates of current satellites, reflecting the orientation of this option toward the current market for raw data as

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opposed to a broader and more expensive focus that would include developing and operating research and development sensors. The cost of returning to the public sector would be higher, since an effort would be made to raise the state of the art rather than merely to serve the current market. The cost of the international consortium option could be half that of returning to the public sector, because of international cost sharing.

Estimates of the federal spending required under each option are shown in Table 10. The estimates do not include offsetting revenues from data sales and international ground station access fees, or federal spending on data purchases and research and development. Part of the offsetting revenues from data sales would in effect be a transfer from one part of the federal government to another, since the government

TABLE 10. ESTIMATED SPENDING FOR REMOTE SENSING OPTIONS, 1992-2000 (In millions of 1990 dollars)

Option	Space Segment[a]	Operations	Total
Commercialize Operation and Distribution	530-800	0	530-800
Return to the Public Sector	1,230	150[b]	1,380
Create an International Consortium	615	100[b]	715

SOURCE: Congressional Budget Office.

a. Space segment costs include those for two additional Landsat-scale spacecraft, sensors, launches, and ground investment. Estimates are taken from a range of configurations in Earth Observation Satellite Company, *Landsat 7: A Comprehensive Study* (January 1989), p. 15. The estimate for the option to commercialize operations and distribution is EOSAT's preferred configuration. The higher estimate for a return to the public sector is based on a configuration that includes research sensors. The international consortium estimate is set at half of the public-sector option estimate to illustrate the potential savings to the U.S. government of international cost sharing.

b. Assumes continued support for Landsats 4 and 5, and $20 million annual operating costs beginning in 1996. Excludes revenues from private data purchases and international access fees that could offset a substantial part or all of these costs.

would probably maintain its position as the most significant customer for remote sensing data.

Other Issues. Each of the three options would carry a number of advantages and disadvantages aside from its effect on federal outlays. They would all share the advantage of providing the data currently available through Landsat to its many users. They would have the common disadvantage of deterring new private investment in remote sensing by providing federal support to a specific competing system.

Emphasizing Private Investment. Maintaining the private sector as an operator of Landsat would probably permit the current assortment of land remote sensing data to be produced at the least cost to society. EOSAT's track record supports the belief that private enterprise, with its freedom to make new cost-saving investment, can lower production cost. Moreover, if satellite costs were shared between the federal government and the private operator, and the federal contribution limited to a fixed amount, the government could avoid the risk of overruns in satellite construction--as it has in the current arrangement to build Landsat 6. A private contribution to capital cost would have to be reflected in higher prices paid by users for data, which would doubtless limit the demand for data. In the long run, however, keeping private investment in remote sensing alive would retain the possibility of commercializing the entire system, or of broadening the scope of private investment to include the distribution of data produced by other systems.

The drawbacks of this option arise from the same elements as its strengths. New research and development sensors would not be emphasized. A private operator might have more difficulty than a public operator in reaching an accommodation with the public operators of future systems like EOS, thus establishing a potential conflict between the public and private sectors. Finally, privatizing the operation of future Landsats would not solve some of the current problems that the system is perceived to have. For example, data would not be provided to researchers without charge. The solution to this problem would be to treat data as a cost of research and include this cost in the funding of research projects.

Should EOSAT be retained as an operator of the system under this option? Any change from the current organization of production would introduce new stress in a system that has already been transferred from one federal operator to another and then to EOSAT. A new operator would essentially start from point zero yet again. Moreover, EOSAT maintains that the vision of commercialization embodied in its 1985 agreement with the government--a vision including two satellites, Landsat 7 and Landsat 6--is still viable.

One drawback to maintaining EOSAT as an operator, particularly if the arrangement was worked out through negotiation rather than through an open solicitation or auction, would be that operating a Landsat system with the federal government carrying part of the capital cost might prove very profitable. An open auction for the rights to distribute data would be one way to limit profits, although EOSAT would certainly enjoy an advantage in such a competition. Another alternative would be direct negotiations between the government and EOSAT, although this approach would be sensitive to charges that the government had been a weak bargainer. EOSAT's status as a wholly owned subsidiary of the likely manufacturers of a new satellite--Hughes and General Electric--would add a further complication. One solution might be to apply some of the methods used in public utility regulation to limit prices and profits.

Returning Landsat to the Public Sector. A return to public operation would be consistent with the belief that the net benefits to society are greatest when available data are as widely distributed as possible, and when new sensors and new types of data are being aggressively developed. The aim would be to maximize social welfare by maximizing benefits, including the unpriced public benefits of new applications that might or might not have potential in the private market. Satellites would carry not only sensors for which there was an established or anticipated market, but also experimental instruments.

Public operation would also be consistent with the declining-cost characteristics of the current industry, and with the legal prohibition on price discrimination. Data could be priced at the marginal or additive cost of production, an efficient solution from society's point of view. The gap between revenues and costs would be closed by subsidies, a practice that is justified when the total value of benefits exceeds their cost of production. A complication in this solution is the apparent ability of the private sector to lower the cost of processing and distribution, leaving it an open question whether public additive cost would be greater or less than the price charged for data by a private operator, even if this price reflected a contribution to the fixed costs of the system. The strategy of returning Landsat to the public sector would emphasize the benefits to be gained from a wide distribution of currently produced data, as well as from research and development and the production of new data, and would rely on the federal operator to adopt additive costs as a basis for pricing. Pressure within the government would possibly tend to push up prices in order to recover costs. Such pressure occurred in setting prices for the private use of NASA's space shuttle, when the price to private users was driven above the level of marginal cost.[36]

A fully public provider could choose sensors less suited to commercial market demand, and thus limit the growth of the private value-added sector. But consumers of raw data--among them value-added firms--would receive the full value of the subsidy. To the extent that the value-added market is competitive, the subsidy would be passed through to the ultimate consumer of information. Certain equity problems would remain, however, because among the principal private-sector beneficiaries would be large, profitable private firms--for example, petroleum companies. The obvious solution of raising prices to these users would not be permissible for a public provider.

Returning Landsat to the public sector would require the creation of a new institutional home. The Departments of Interior, Commerce, and Defense would be candidates, as would be the National Aeronautics and Space Administration. A problem common to all of them is that civilian land remote sensing is not an integral part of any agency's current mission. In order to create the type of commitment necessary to make a public solution work well, the Congress would have to provide strong direction and funding.

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36. Congressional Budget Office, *Pricing Options for the Space Shuttle* (May 1985), chap. IV.

Among the agencies mentioned, the Defense Department stands out as the single most significant purchaser of data and for its expertise developed in operating the military remote sensing system. The civilian character of the expected benefits, however, points toward a civilian home. One answer would be to allow a civilian agency or combination of agencies, for example the Department of Agriculture or the Department of the Interior, to distribute the data produced by a Defense Department system.

The current involvement of the Commerce Department in operating the weather satellites and in promoting new ventures in remote sensing through its Office of Commercial Space points toward that department as a potential home base. NASA would offer similar advantages of technical competence and recent experience in the market, as well as a current plan to expand greatly the nation's general remote sensing capability by developing the Earth Observation System. NASA also enjoys close links with the community of scientists likely to use Landsat data. Interior's historical role as the operator of the data distribution system and a significant user of remote sensing data underlies its claim.

Creating an International Consortium. This option would require pooling and distributing data from the existing independent systems of the United States, Europe, Japan, Canada, the Soviet Union, and other interested countries. By the mid-1990s, as existing spacecraft reached the end of their lives, new systems would have to be launched. A consortium would define, procure, and be responsible for the launch of these systems. Membership would almost certainly extend beyond countries with spacecraft in orbit to those with ground stations, and even beyond them to countries without any investment in remote sensing. Forming this type of consortium would require international agreement on national contributions, pricing policy, geographic marketing rights, revenue sharing, contracting procedures, and the attributes of future satellites.

On the assumption that a set of terms was available that could be accepted by all parties, creating an international consortium would also require a complex transition from the current system to the new arrangement. Revenues in excess of costs would probably not be a lubricant smoothing the transition, since the creation of a consortium would not in itself create demand sufficient to cover the full cost of a remote sensing system on the scale of Landsat or SPOT (unlike the experience of the Intelsat international communications organization). Private investment in general, and EOSAT in particular, could play a role in a consortium.

A consortium would offer two principal advantages. Costs could be shared among the international partners, avoiding the duplication of facilities that is likely to occur without an international agreement. However, if satellite procurement and design reflected political rather then technical requirements, these savings would be decreased. An international consortium could also deal with the problem of decreasing costs by adopting a policy of price discrimination, without running afoul of the access problem. The broad international membership of a consortium would mitigate the suspicion that technically advanced rich nations and their corporations might take advantage of less advanced poor nations. To maximize social benefits, a consortium could sell data to poorer countries at prices as low as the additive cost of producing data, and compensate through higher revenues from sales to the private sector and to governments willing to pay higher prices.

A disadvantage of an international consortium for the United States would be the loss of control over data important for national security. Another disadvantage is the possibility that such a consortium might impose limits on competition and private investment at some time in the future.

CHAPTER IV

MATERIALS PROCESSING IN SPACE: MICROGRAVITY RESEARCH AND ORBITAL FACILITIES

The virtual absence of gravity in space affects the way materials respond to manipulation. Low gravity offers the possibility that materials useful to the chemicals, pharmaceuticals, and electronics industries could be better understood or perhaps even manufactured in outer space.[1] In the early 1980s, some people hoped that products manufactured by orbiting factories might acquire multibillion-dollar markets by the turn of the century. This potential for private investment became one of the reasons for government investment in space and the first serious economic justification for people in space. While experience has deflated these expectations, current policy in the United States and abroad is predicated on the assumption that materials processing in space will eventually be of economic benefit.

In the United States, the economic potential of microgravity continues to be a reason given for building the space station and for spending smaller sums on microgravity science and on promoting private investment in microgravity experiments. In appropriating funds for 1991, the Congress directed the National Aeronautics and Space Administration (NASA) to make microgravity processes the first priority of the space station.[2] In the future, the Congress could grant additional priority to microgravity materials processing by increasing spending in related science and promotional activity. Another option would be to increase the funding for microgravity research that is independent of the current program's primary emphasis on the space shuttle and the space station. Among these alternatives are privately financed and operated orbital facilities.

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1. The discussion in this chapter is confined to the microgravity of low Earth orbit. The possibility of creating an ultra-high vacuum in Earth orbit has also attracted scientific and commercial interest. See, for example, "Space Semiconductor Research Planned," *New Technology Week* (June 20, 1988), p. 8.

2. Congress of the United States, *Conference Report*, Report No. 101-900 to accompany H.R. 5158, 101-2 (1990), pp. 41 and 42.

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THE CURRENT OUTLOOK AND POLICY OPTIONS

The last 10 years have confirmed that processing materials in space is an expensive, high-risk activity that is not likely to produce economic returns in the near future. McDonnell Douglas's attempt to produce drugs in space is perhaps the best example of this experience (see Box 6). Consequently, the private sector has not invested substantial resources in microgravity activity.

Nor is there much evidence to support public investment in space processing. Federal support for basic research in that field can be justified on the ground that private businesses invest too little in areas where there is not much hope of an immediate payoff. Yet, even as a basic research activity, the results to date have been discouraging. Space manufacturing is not likely in the foreseeable future, even though some of the experiments have been positive (for example, larger and better-formed protein crystals potentially useful to the pharmaceuticals industry have been grown). Despite substantial expenditures, not enough time has been spent on orbit to determine whether or not the processing of materials there could ultimately bring a significant economic return (see Box 7).

No single country or group of countries spends as much as the United States does in exploring the scientific and commercial prospects of microgravity, counting the cost of investments in space transportation facilities and their operation. The entire European effort, including the European Space Agency and all national programs, is comparable with the U.S. program, but has less access to the U.S. space shuttle with its resources for astronaut-tended experiments. The Soviet program has superior orbital facilities and access to space, but lacks the national technical and industrial base to make use of these facilities if microgravity research proves commercially useful. The Japanese effort is smaller than the U.S., European, or Soviet programs. The Centers for the Commercial Development of Space sponsored by NASA compare well with Europe's Intospace and various hybrid Japanese institutions as a way of maintaining private interest in commercializing microgravity processing should such prospects occur.

BOX 6
McDonnell Douglas and Space Manufacturing

In the late 1970s, McDonnell Douglas initiated the most substantial attempt to produce a product in space. In partnership with the Ortho Pharmaceutical Division of Johnson and Johnson, McDonnell Douglas attempted to employ a sophisticated separation and purification process, electrophoresis, to produce erythropoietin--a drug used to treat patients who do not produce sufficient red blood cells. The attempt proved unsuccessful for a number of reasons, among them undue optimism concerning the reliability of the shuttle system and the development of ground-based biotechnical alternatives to space processing.

McDonnell Douglas began ground development of the electrophoresis process in 1977. As early as 1978, a McDonnell Douglas executive saw the connection between erythropoietin and electrophoresis as a space technology of the future.[1] A 1983 report, prepared in support of the National Aeronautics and Space Administration's space station program by McDonnell Douglas, identified 12 pharmaceutical products as candidates for manufacture by electrophoresis in space. Assuming that space-produced products would gain 75 percent of their respective markets, the study estimated $7.2 billion dollars in annual sales in the United States alone, and as much as $20 billion annually if the European and Japanese markets were included. At this early point in the project, McDonnell Douglas's business plan included clinical testing and approval by the Food and Drug Administration by the mid-1980s, followed by commercial production of the first space drug by 1986.[2]

McDonnell Douglas's expectations remained high during 1984, despite delays that pushed back the schedule for initial production into the late 1980s, and for full production of four different drugs to the mid-1990s. NASA continued to offer support by providing free research flights on the shuttle. Negotiations continued with the Fairchild company to lease several unmanned spacecraft to accommodate the production volume anticipated by McDonnell Douglas. These "Leasecraft," as the hardware was called by Fairchild, were to be launched by the shuttle and left in orbit, where the product would be produced by a fully automated process and subsequently retrieved and returned to Earth by the shuttle. NASA was supporting Fairchild's development of the Multimission Modular Spacecraft, a spacecraft similar to the one McDonnell Douglas was seeking to lease, and had agreed to provide an initial free shuttle launch and retrieval for the commercial version of the Fairchild spacecraft.[3]

By 1985, Ortho had withdrawn from the partnership in favor of a ground-based biotechnical alternative developed by a genetic engineering company, Amgen. Up to that point McDonnell Douglas had flown two experimental flights. While it was experiencing some problems, the company remained convinced that the process would work, and that it would be improved, rather than made obsolete, by developments in biotechnology.[4] Some estimates place McDonnell Douglas's investment in the venture through 1985 at up to $60 million.[5]

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1. E.F. Branahl, "Advanced Materials Processing Technology," in "Space Industrialization: A New Era," *Business Week*, September 25, 1978.

2. H.L. Wolbers, *Space Station Needs, Attributes, and Architectural Options: Commercial Opportunities in Space*, prepared for the National Aeronautics and Space Administration (Huntington Beach, Calif.: McDonnel Douglas Astronautics Company, April 1983), pp. 85-99.

3. "Medicine Sales Forecast at $1 Billion," *Aviation Week and Space Technology*, June 25, 1984, pp. 12-14.

4. "McDonnell Douglas Should Generate Revenue by 1988 in Space-Based Bioprocessing," *Commercial Space*, Fall 1985, pp. 49-51.

5. Euroconsult, E.C., *Prospects for Microgravity Research in the USA, Europe and Japan* (Paris, September 1988), p. 10, indicates that McDonnell Douglas wrote off a $12 million expenditure on equipment. In an interview on May 17, 1989, James Rose, former program manager of the McDonnell Douglas effort, estimated the company's total investment over the life of the project at $60 million.

BOX 7
Commercial Applications of Microgravity

Gravity and mass grant objects their weight and, in turn, influence buoyancy and convection. The absence of gravity removes buoyancy as a consideration in growing crystals, obtaining purified substances in separation processes, and obtaining uniform mixtures of the different parts of metal alloys or polymers.[1] As a consequence, the electronics, pharmaceuticals, chemicals, plastics, and metals industries have expressed interest in the possibility of exploring the microgravity environment. The absence of gravity also permits weaker electrical or acoustic forces to position liquid materials, removing the possibility that a container will chemically interact with its contents. Containerless processing based on these technologies may have applications in the metal, glass, and ceramics industries.

Pharmaceuticals, chemicals, and electronics companies have shown interest in space processing. Crystal growth experiments are currently the activity most pursued by the pharmaceuticals industry. Shering Plough, Merck, Upjohn, Elli Lilly, and Burroughs Welcome are providing limited support. Genentech is working with the National Aeronautics and Space Administration Center for the Commercial Development of Space to learn more about disease processes in which bone and cell structures deteriorate. Electronics producers have periodically expressed interest in growing crystals of semiconductor materials. Chemical and materials producers, most prominently 3M, support research in metals and alloys, among them superconducting materials.

The current model of corporate commercial interest in microgravity space processing is the 3M program. At present, 3M has a 10-year agreement with NASA to fly 62 experiments. The 3M program is focused on research that will be applied to Earth-based products and processes, rather than on the development and manufacture of products in space. The first experiments in the program, designed to study organic compounds in crystalline form, were flown on the shuttle in 1984. The research is open-ended, but is seen by 3M as potentially applicable to electroptical systems. To date 3M has applied for two patents on the basis of its space experiments, one for a new crystalline material and another for a processing technique potentially applicable to the Earth-based manufacture of an improved optical disk for laser recording. The most likely source of near-term revenue for the 3M venture may be the provision of support services and hardware for other companies that wish to perform microgravity experiments.[2]

The 3M program is unique in its scope and corporate commitment. Its general characteristics contrast with the earlier emphasis on space manufacturing, and are likely to be a model for commercial exploitation of microgravity for the foreseeable future. The immediate goal is to achieve results similar to those that would be produced by a corporate research laboratory engaged in basic research: projects that could move forward into more applied research, and preemptory patents that might or might not prove their worth in the future.

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1. National Research Council, *Industrial Applications of the Microgravity Environment* (Washington, D.C.: National Academy Press, 1988), p. v

2. "3M Moves into New Research Phase with Polymer Experiment on Shuttle," *Aviation Week* and *Space Technology* (December 19, 1988).

Private involvement in materials processing in space has yielded some benefits, even though much less has been invested in it than in the exclusively government effort. The main U.S. thrust has been on use of the space shuttle as an orbiting laboratory and on the planned space station. This effort has been beset by delays and problems over the last decade. The far less expensive efforts to promote private interest in microgravity through the NASA Commercial Use of Space program has proved flexible enough to accommodate to changing circumstances, and in doing so produced a stream of relatively low-cost results having scientific, technical, and potential commercial value. Efforts to involve privately funded and operated orbital facilities are being expanded in the hope of further increases in productivity. While the large-scale activities of the primary program will be ultimately necessary to answer key questions about the value of microgravity, the commercial program results to date have shown that useful scientific and technical results can be delivered at a relatively low cost.

Policy options exist in several different areas. The Congress could increase or decrease spending levels in several parts of NASA's budget: in the space station development program, in the Space Science and Applications program's research and development activities, and in the research and promotional efforts of the Office of Commercial Programs. It could also allocate more or less of the capability of NASA's space infrastructure--the space shuttle primarily--to processing materials in space. NASA's 1991 budget includes funds to increase capacity to support space processing by procuring and leasing additional space transportation and orbital facilities from the private sector. This is a step in the direction of more autonomy for the commercial program from the shuttle/station primary thrust, and could be pursued as an option not only for the commercial program but also for NASA's strictly scientific efforts in materials processing in space.

CONDITIONS OF SUPPLY

Public spending on facilities, science programs, and procurement of services is the determining condition of supply for microgravity experiments. Public funds provide for space transportation and orbital facilities, and drive their use through research and development programs.

A combination of public and private funds pay for most experiments designed by the private sector. In the United States, Europe, and Japan research efforts are focused on using the space shuttle to prepare for later use of the space station. The Soviet Union uses its own facilities, most notably the space station MIR, to conduct a program similar to those in the West. The Western programs, faced with delays in their primary efforts, have turned to private and Soviet orbital facilities.

Private orbital facilities, used in conjunction with the space shuttle or independently, are seen as a means to accelerate progress in microgravity science and its commercial applications. Current and proposed efforts, mostly in the United States, are focused on small-scale experiments. The operators of private facilities may be able to offer potential experimenters the advantage of a simpler transaction by handling complex but repetitive procedural requirements--for example, meeting shuttle flight safety regulations. Private facilities are not costless to the government, however. The public sector must purchase all or most of the capacity brought to the market in order for a private facility to be financially viable. In some cases, this mode is more costly than the outright purchase of a facility by the federal government. While current U.S. spending on private facilities is relatively small, new programs approved for 1991 will increase these expenditures.

The United States

The primary thrust of the U.S. effort to develop materials processing in space has focused on using the space shuttle and its "Spacelab" payload.[3] In its original conception, private investors were to be involved in this process primarily as users of the public program's research results and infrastructure. Problems in the primary effort, most notably delays in the shuttle flight schedule, have led to alternative plans.

3. The Spacelab system includes pallets that carry experiments in the shuttle orbiter's payload bay and a modular laboratory that is an extension of the habitable volume of the orbiter. The laboratory module is used extensively in processing materials in space, and carries more sophisticated experimental equipment than the shuttle middeck or the proposed "Spacehab" extension.

Most of these plans have included a role for privately financed and operated systems that have the NASA program as their primary or exclusive customer. Another option would be to use foreign facilities to accelerate the progress of the U.S. program.

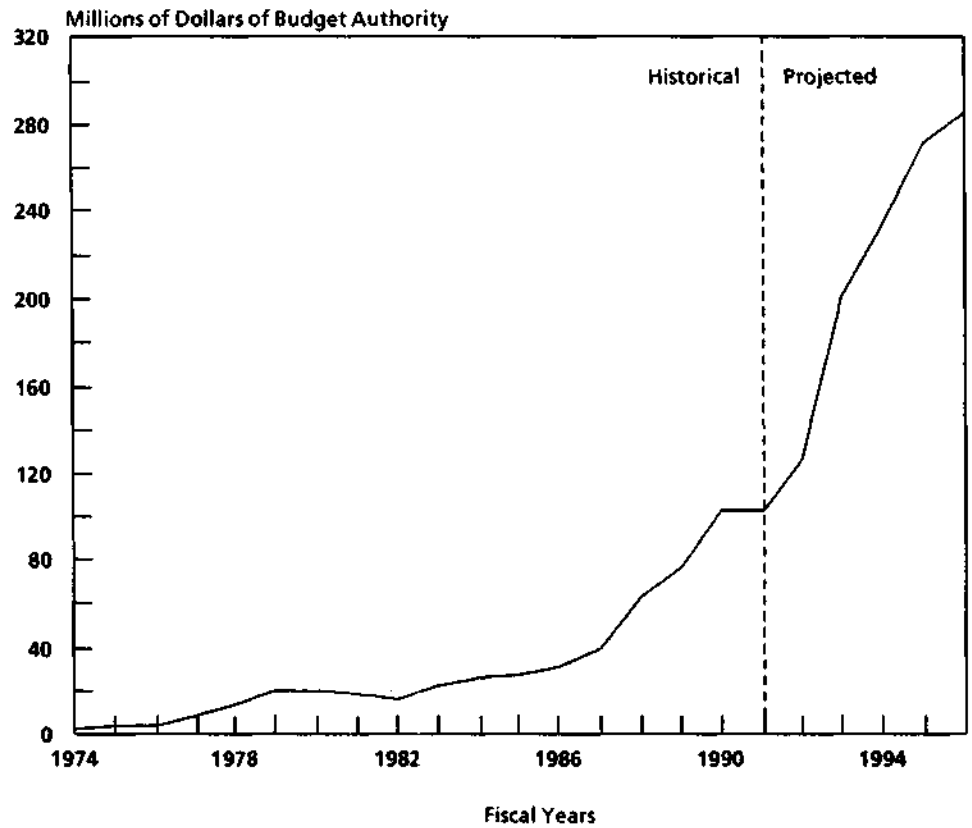
The Primary Effort. The U.S. microgravity science program seeks to increase the understanding of the influence of gravity on Earth-based processes, to produce limited quantities of exotic materials with enhanced properties for specialized applications or comparison with materials produced on Earth, and to develop space processing technology for scientific and commercial application.[4] Its activities tend to be expensive and larger in scale than the commercial programs. Scale in microgravity experimentation is defined by some combination of the mass of the equipment needed for an experiment, the extent of human intervention necessary, and the quantity of electric power required. A Spacelab mission, for example, requires the shuttle's whole cargo bay, usually involves two or more crew members for the entire flight, costs up to $500 million for experiments and equipment, and must be planned several years in advance. (Some significant commercial experiments, in contrast, have cost under a $1 million and have been carried on the shuttle in its crew compartment at very short notice.) The shape and dimensions of the present microgravity science program represent the judgments of scientists as to what is important in the field, and reflect critical discussions of the program as it existed in the early 1980s.[5]

Funding for materials processing in space by NASA's Space Science and Applications program has increased rapidly since 1985 in anticipation of major space shuttle Spacelab flights and the beginning

4. National Aeronautics and Space Administration, Microgravity Science and Applications Division, *A Program Overview: 1986-87* (1987), p. 6.

5. A series of internal and external reviews found the NASA science program of the early and middle 1980s to be deficient in scientific content and management. See National Research Council, *Report of the Committee on Scientific and Technological Aspects of Materials Processing in Space* (Washington, D.C.: National Academy of Sciences, 1978); National Aeronautics and Space Administration, *Final Report: Microgravity Materials Science Assessment Task Force* (1978); National Research Council, *Review of the Microgravity Science and Applications Programs: January-March 1987* (Washington, D.C.: National Academy of Sciences, 1987); and National Research Council, *Industrial Applications of the Microgravity Environment* (Washington, D.C.: National Academy Press, 1987), p. 5.

Figure 1.
Historical and Projected Funding for Microgravity Science



SOURCE: Congressional Budget Office, from National Aeronautics and Space Administration.

of space station operations in the late 1990s (see Figure 1). The 1991 appropriation of $100 million would be almost tripled by 1996, according to NASA's 1992 budget plan. A significant part of current funding is being spent to develop six multi-user pieces of equipment for the space station, for research in crystal growth, biotechnology, and metals and alloys.[6]

6. National Research Council, *Industrial Applications of the Microgravity Environment*, p. 41.

Funds directly allocated to science and technology programs do not cover the full cost of the primary national effort to explore the possibilities of microgravity. Transportation and operating costs must also be figured in. The commitment to use the shuttle for microgravity research, as indicated by NASA's June 1989 shuttle schedule, represents the equivalent of six dedicated shuttle flights, or a budgetary commitment of approximately $400 million (in 1990 dollars) over six years.[7] Other operating costs, primarily those necessary to support major pieces of hardware flown on the shuttle--the Spacelab, and foreign retrievable platforms--are also substantial.[8] Microgravity is a coequal partner with life sciences, astrophysics, and Earth observation in using the Spacelab system, the most prominent operating cost item. The NASA budget for 1991 included almost $130 million in funding for Spacelab.[9] Were spending to increase in accord with the NASA budget plan underlying the 1991 budget request, spending would climb to $160 million in 1995.[10]

The primary national effort to explore microgravity has consistently fallen short of its objectives, mainly because of delays in the shuttle system. In 1979, NASA projected an annual shuttle flight rate of almost 60 flights by the late 1980s.[11] Current expectations are for 8 to 10 flights annually. Even science missions included in the January 1989 NASA flight schedule are beginning to be moved back as a consequence of the flight delays in the summer of 1990, and the planning and replanning that tend to occur when experimental activities are delayed.

An Alternative Path. Another way of pursuing a microgravity program would be to perform more smaller experiments, either by adding to the shuttle system's present capability or through independent

7. NASA estimates the marginal cost of a shuttle flight to be $70 million.

8. Retrievable platforms carry experiments requiring long duration but not human attention. They can be launched by a traditional rocket or by the shuttle, remain in orbit for a period of time, and are subsequently retrieved by the shuttle.

9. *NASA Budget Estimates, Fiscal Year 1992*, p. RD 2-1.

10. National Aeronautics and Space Administration, Office of the Comptroller.

11. Congressional Budget Office, *Setting Space Transportation Policy in the 1990s* (October 1986), p. 11.

facilities. Smaller-scale experiments tend to be of less scientific importance than those undertaken in the primary program. For example, it is well established that larger protein crystals can be grown in space; there is no need to demonstrate this fact. But its application to growing a particular crystal may be of interest. For experiments of this type, facilities permitting small-scale experiments, either public or private, are more resilient in the face of shuttle delays. Small-scale experiments can be flown as a secondary payload on the shuttle or on relatively small unmanned rockets. Since many such experiments are from the commercial, as opposed to the science, microgravity program, they have led to an increasing interest in privately developed and operated orbital facilities.

The 1991 budget of NASA's Office of Commercial Programs includes $14 million in funding to lease a Commercial Middeck Augmentation Module--a competition won by Spacehab, Inc., which had marketed its Spacehab product since 1984.[12] This orbital facility for microgravity experimentation will occupy a quarter of the shuttle orbiter's cargo bay and be a habitable pressurized area where crew members can tend experiments. It provides about 70 lockers that could carry 3,000 pounds of experiments and equipment, and about half of the power that is available to experimenters who use the larger and more expensive Spacelab. Seven flights are scheduled through the mid-1990s. Two-thirds of this capacity will be used to fly off part of NASA's scientific and commercial microgravity backlog. The remainder will be sold to foreign governments and private industry. Mitsubishi and Aertalia will market Spacehab services in Japan and Europe, and 3M will cover the U.S. market.[13] NASA estimates that the entire project, including lease payments and its own expenses, will require $180 million through 1995.

NASA has also moved ahead with a privately financed effort to extend the duration of a shuttle flight from 10 to 16 days. The NASA 1990 budget first proposed exploring a leasing or financial partici-

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12. Department of Commerce, *Commercial Space Ventures--A Financial Perspective* (1990), pp. 18-24, provides a history and description of the Spacehab venture.

13. Euroconsult, *World Space Industry Survey, Ten Year Outlook, 1989/1990 Edition* (Paris, 1990), p. 336.

pation agreement with a private investor to develop an Extended Duration Orbiter (EDO) pallet to be carried in the shuttle cargo bay. An agreement between NASA and the Rockwell International Corporation provides for Rockwell to finance a part of the EDO, in exchange for the right to market the use of the payload to paying corporate or foreign customers.

While the Spacehab and the EDO can increase the experimental productivity of a shuttle flight, both are ultimately tied to the system. NASA is also developing access to space completely independent of the shuttle. The Commercial Experimental Transporter (COMET) is to be a returnable capsule system that will use a small unmanned rocket and capsule to conduct automated experiments. The commercial aspect of the project is the "hands-off" position NASA will adopt in the design and integration of the system. Service requirements will be specified, but not the details of the hardware necessary to meet them. Moreover, the service requirements will reflect the needs of commercial experimenters at the NASA centers for the Commercial Development of Space, rather than the science program. Ultimately, however, government funds will provide most of the initial demand for COMET. Cost-plus contracts for part of the project will limit private financial risk. Independent research on microgravity could be further accommodated by using foreign systems, in particular the Soviet space station MIR.

Europe

The European microgravity science effort is comparable with the U.S. program both in current activities and in its goals.[14] Like the U.S. effort, its primary focus is on space shuttle experimentation leading to future use of the space station. During the first half of the 1990s, the

14. Euroconsult, "Prospects for Microgravity Research in the USA, Europe and Japan," as summarized in *Space Policy* (May 1989), p. 169. The article cites a recent comparative analysis of national microgravity efforts sponsored by the European Community, which found that in 1988 total European public expenditure for microgravity R&D--the sum of the cooperative European Space Agency program and individual national programs--stood at slightly less than 110 million European Currency Units, compared with a U.S. budgetary equivalent of over 100 million

(Continued)

European program calls for two Spacelab missions, three unmanned platforms to be retrieved by the shuttle, participation in International Material Lab SpaceLab missions, and use of Spacehab. The umbrella for Europe's investment in the space station is the Columbus program. At an estimated cost of $4.75 billion, the program will develop a laboratory module to be attached to the international space station, a free-flying man-tended platform to be flown in formation with the space station, and a polar-orbiting unmanned spacecraft.[15]

Europe's effort is led by the multinational European Space Agency (ESA) program and Germany's national program. Germany has accumulated considerable experience in space processing as the largest contributor to the development of the Spacelab module and by supporting the dedicated Spacelab flight, D-1, in 1985. The claim of European success in microgravity research is in large part based on the success of this flight. Current efforts are focused on preparing experiments for two additional Spacelab flights, D-2 and D-3, scheduled to fly on the shuttle in 1991 and 1994, respectively. The cost of D-2 is estimated to exceed $500 million.[16]

France and Italy also have active programs. For example, Italy will eventually spend over a billion dollars on Europe's contribution to the space station, and has recently invested $25 million in a ground facility to process microgravity experiments.[17]

In its search for short-term alternatives, Europe has not emphasized the public role in assuring the market for private facilities as the

14. Continued

European Currency Units. This same evaluation placed Europe's effort on a par with or above the U.S. program, because "Europeans have not been promoting commercial applications at the expense of basic and applied research, as has been the case in the U.S." The conclusion reflects a judgment similar to that rendered by U.S. reviewers of the pre-Challenger U.S. effort, and recognizes the failure of the hopes for quick manufacture of useful products in space. The cost comparison presented by Euroconsult does not include the total cost of microgravity activity for either program. Facilities investment, operating cost, and transportation cost are not fully included in either the U.S. or European figures.

15. *Space News*, May 7-13, 1990, p. 3.

16. *Space News*, August 6-12, 1990, p. 35.

17. *Space News*, August 6-12, 1990, p. 32.

United States has done. Instead, publicly supported European experimenters have purchased access to space from a variety of sources, among them the Soviet space station MIR. Germany has arranged to fly an astronaut and associated payload of 200 pounds on MIR at a cost of $12 million. France has a similar arrangement.[18] This would also be a technically viable option for U.S. experimenters, in limited applications.

The Soviet Union

In its emphasis, approach, and results so far, the Soviet effort is similar to Western programs, though not much is known about its costs.[19] The focus of Soviet activity during the 1980s was on separation technique for obtaining ultrapure substances, crystal growth to explore molecular structure, and uniform mixtures of plastics and metal alloys to create new materials. The industrial sectors seen as benefiting from the Soviet program included electronics and pharmaceuticals. Investments were made in equipment, including furnaces and biological separating apparatuses. Industrial results have been very limited, and the future of Soviet space processing remains uncertain.[20]

The Soviet Union is at present the only country operating a continuously manned laboratory in space, the MIR. Materials processing experiments are conducted on this facility and on an independent unmanned carrier based on the Soyuz spacecraft. Both facilities are offered to foreign public and private experimenters for a fee. Payload Systems, Inc., a small U.S. firm, has flown a payload on the MIR and hopes to market this experimental capacity to international drug companies.[21]

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18. *Space News*, August 6-12, 1990, pp. 38 and 44.

19. Congressional Research Service, *Soviet Space Programs: 1981-87, Part 1* May 1988) and *Part 2* (April 1989) provide a comprehensive review of Soviet space activity, including space processing, during the period.

20. Congressional Research Service, *Soviet Space Programs, Part 1*, pp. 22-24, 83-88.

21. Jeffery K. Mauber, "Perestroika in Orbit," *Across the Board, The Conference Board Magazine* (July/August 1990), pp. 51-55.

The productivity of the Soviet space station has been questioned by some observers.[22] Recently, however, with growing experience and with the addition of a new module, the Kristall (which has six furnaces and four chambers for separating biological agents), the MIR's capability has increased.[23] Press reports indicate that the crystals produced on the MIR are worth millions of dollars, although the buyer is unidentified. This improved capability will be under increased scrutiny. Recent political and economic changes in the Soviet system have brought demands that the civilian space program produce more direct and tangible benefits.[24]

Japan

The broad outlines of the Japanese space program and its microgravity effort were presented in a 1989 planning document.[25] The plan projects that public expenditures of $23 billion and private spending of half that amount will be required to meet Japan's space objectives between 1986 and 2000. In the Japanese reckoning, its public spending will amount to roughly one-tenth of the spending of the United States, Europe, and Japan combined. Japan plans to contribute a laboratory module, the Japan Experimental Module, to the U.S. space station program at a cost of $2.5 billion.[26]

Japan's public expenditures on microgravity R&D have been estimated at $50 million in 1987 and $65 million in 1988, and are likely to grow moderately to support planned activities.[27] The Science and Technology Agency has supported microgravity research since 1982,

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22. "The Tribulations of a Space Station," *The New York Times*, March 13, 1990, p. C-1.

23. *Space News*, April 2-8, 1990, p. 6.

24. Simon Baker, Stephan Chernard, and Phillip Clark, "Soviet Space at the Crossroads," *Space Markets* (January/February 1990), pp. 6-27, and "Soviet Woes Tarnish Once-Shining Space Efforts," *The New York Times*, January 8, 1991, p. 21.

25. "Outline of Japan's Space Policy," Space Activities Commission, Japan, June 28, 1989.

26. "Japan Begins $2.5 Billion Effort to Develop Freedom Station Module," *Aviation Week and Space Technology* (August 20, 1990), p. 79.

27. Euroconsult, E.C., *World Space Industry Survey: Ten Year Outlook 1988 Edition* (Paris, April 1988), pp. 333-336.

using aircraft and sounding rockets. Both basic science and commercial applications are being pursued. Major events scheduled in the near term include a Japanese Spacelab mission in 1991, the First Materials Processing Test, that will include 34 experiments. The Japanese program also includes a free-flying unmanned experiment program, the Free Flyer Unit, to be launched on a Japanese rocket and recovered by the U.S. shuttle in 1993. The Japanese also plan to participate in International Microgravity Laboratory flights during the 1990s.

Private Orbital Facilities: Their Cost and Productivity

U.S. private investment in materials processing in space has produced a stream of scientific and technical results based on small-scale experiments. The current policy encouraging private investment in orbital facilities will expand the opportunities for this class of experiment. The question is whether private development, ownership, and operation of these facilities justifies their cost to the government.

Those who advocate promoting new private investment in orbital facilities imply that it is difficult for potential private experimenters to work with the public bureaucracy and that government orbital facilities are overdesigned and too expensive. The latter criticism may stem primarily from the fact that public experimental equipment is designed to meet the productivity goals of the space station during the next century, while private orbital facilities are designed for current requirements.

Government purchases of private services may not be cheaper than ownership, if the government is the sole or preponderate user of the facility, because the government's cost of capital is lower than the private sector's. The National Academy of Public Administration analyzed a proposal that the government lease a small commercial space station. It found that even when the government leased only 70 percent of the use of the facility, the cost to the government of leasing exceeded that of an outright purchase.[28] The Congressional Budget Office reached a similar conclusion in reviewing seven projects proposed for private financing in NASA's 1990 budget request.[29] This finding probably holds for most private orbital facilities.

One of the aims of those who advocate federal support for private orbital facilities is to change the division of risks between the government and the private investor. Traditionally, the government has assumed technical, financial, and market risk: it has supervised design and production under cost-plus fixed-fee contracts, and bought the capital asset when completed. The private investor's risk has been limited to performing within the specifications of the contract. In the case of orbital facilities, contracts have usually recognized that unforeseen technical problems may occur and permitted adjustments in cost to overcome them.

A new strategy intended to change the division of risk would promote private investment in orbital facilities through "anchor tenancy." The government in its role of anchor tenant would be committed to buy a large part of the service initially provided by an orbital facility, thus decreasing the private investor's exposure to market and financial risks. While these risks might reenter the picture after the initial period of intensive government use, in the interval the private operator would have a chance to demonstrate the value of the facility to markets beyond the government. At the same time, technical risk should move away from the government toward the private producer.

While the government would refrain from directly managing the project, the use of fixed-price contracting would lower its exposure to the risks of overruns and delays caused by technical problems. Fixed-price contracting would make it possible to test whether the private sector can function as a commercial provider more effectively than the traditional system of procurement.

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28. National Academy of Public Administration, *A Study of the Cost and Financing of a Commercially Developed Space Facility* (Washington, D.C.: April 1989), p.44.

29. Congressional Budget Office, *Preliminary Analysis of NASA Commercialization Initiatives*, Staff Memorandum (February 1989).

The Commercial Middeck Augmentation Module will be provided under a fixed-price lease arrangement. The Commercial Experiment Transporter's services will combine fixed-price and cost-plus contracting, in that cost-plus contracts will cover the development of the experiment carrier and other new technology included in the project. As in traditional procurement, the government will be exposed to delays or increased costs caused by technical problems in developing the transporter. The "commercial" aspect of the Experiment Transporter is limited to the management of the effort by a Center for the Commercial Development of Space.

The ultimate test of policies encouraging private investment in orbital facilities that are used predominantly by the government is whether they will stimulate private investment in microgravity activity. If the private demand for processing materials in space grows, the creation of private facilities will provide needed capacity. If the mere presence of private agents in the current market encourages substantial growth in demand, it is reasonable to see the additional cost of private facilities as an effective expenditure to promote private research and development. The Commercial Middeck Augmentation Module and the Commercial Experiment Transporter can be seen as experiments testing this proposition. Success will provide support for larger public investments in more ambitious private facilities in the future.

CONDITIONS OF DEMAND

Ultimately, the private demand for processing activities in space will depend on its contribution to private output. Firms will choose to pay for space processing--as with any input--by weighing its expected contribution to output and profitability against a set of alternatives. In the near term, the practical factors that will determine the demand for microgravity experiments will be the amounts spent on research and development by industries with a potential interest in microgravity, and governmental efforts to encourage industry to undertake research and development activities.

TABLE 11. RESEARCH AND DEVELOPMENT FUNDING IN INDUSTRIES WITH A POTENTIAL INTEREST IN SPACE PROCESSING, 1987

Industry	Billions of Dollars	Percent of Net Sales
Industrial Chemicals	3.7	4.6
Drugs and Medicines	4.1	8.5
Other Chemicals	1.9	3.3
Electronic Components	3.6	8.7
All Manufacturing	65.0	3.2

SOURCE: Congressional Budget Office from National Science Foundation.

Private Research and Development Spending

Industries with a potential interest in space processing all spend larger than average amounts on research and development (see Table 11).[30] The Department of Commerce estimates the cost of developing a single new pharmaceutical product to be $125 million over 10 years.[31] Intel, a leading U.S. manufacturer of semiconductor devices, is reported to have spent $250 million to develop its "486" computer chip.[32] If space processing proved to be profitable in these industries, it could draw on this pool of funds.

The obstacles to adopting space processing as a research technique in these industries are similar to those that would confront any new technology. Firms tend to compete within a defined research trajectory, improving their products and processes in the same dimension

30. Congressional Budget Office, *Federal Financial Support for High-Technology Industries* (June 1985), p.10., scores three-digit industries as to whether or not they are "high-technology" according to six different standards. Electronic components (SIC 367) and drugs (SIC 283) are high-technology according to all six standards. Two classes of chemicals (SIC 281 and 286) and plastic materials (SIC 282) meet five of the six standards.

31. Department of Commerce, *1989 Industrial Outlook*, p. 16-1.

32. *Wall Street Journal*, April 11, 1989, p. B-4.

from one generation to the next.[33] For example, recent advances in electronic components have typically involved increasing the number of circuits on a chip and lowering the incidence of manufacturing defects. A radical alternative such as space processing carries more uncertainty than patterned research and development, which has an established risk-and-return profile.[34] Government promotional programs essentially seek to reduce the cost of taking alternative paths.

Government Promotion of Commercial Activity

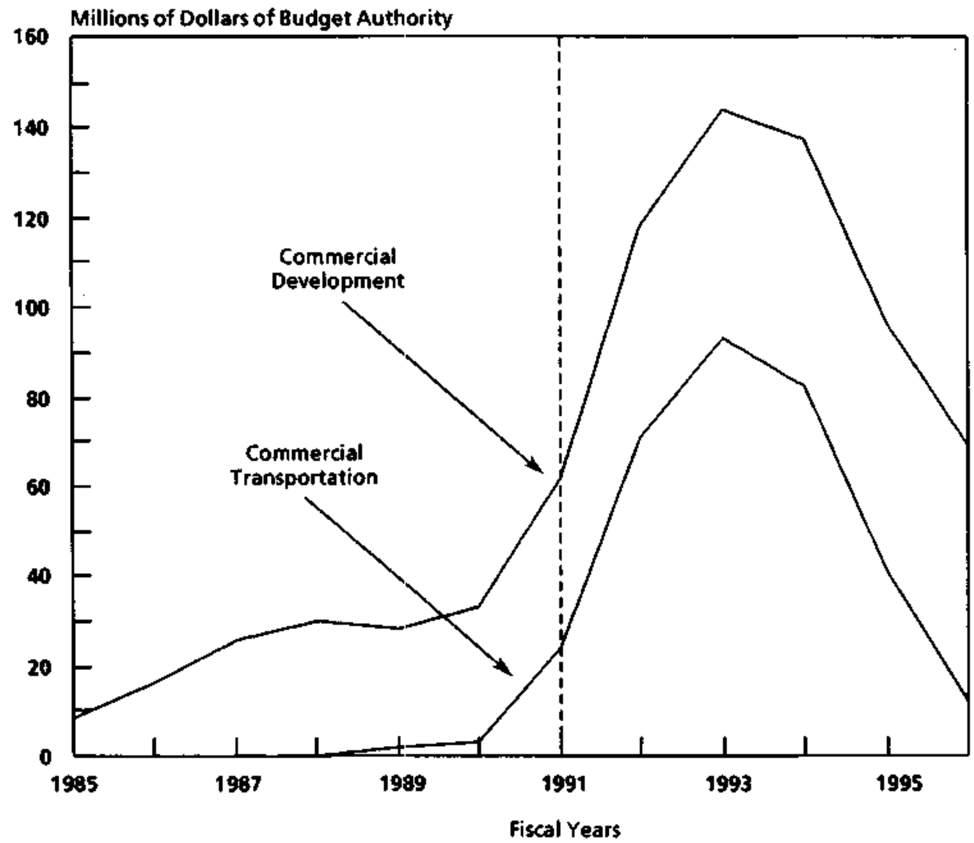
A rationale for federal spending to encourage private demand for processing materials in space begins with the proposition that private firms lack adequate information to make an economically intelligent assessment of this type of investment. The social benefits of successful processing of materials are potentially so great, the argument continues, that the cost of encouraging firms to produce the information necessary to make an informed decision is a prudent social investment. In this context, calling on the private sector alone to pay the cost of gathering information could result in too little spending because no single private firm's return would be sufficient to justify the investment. Within a general framework of competitive research and development, promotional programs attempt to decrease the uncertainty associated with a new research methodology or to lower the cost to the firm of decreasing that uncertainty itself.

United States. NASA's program to encourage the commercial use of space has grown substantially since its initiation in 1983 (see Figure 2). The Office of Commercial Programs is responsible for this budget, and for coordinating the access of the private sector to various parts of the NASA program. The office also negotiates agreements with private firms wishing to take advantage of various NASA programs offering free or deferred-payment flight opportunities. The pro-

33. Giovani Dosi, "Sources, Procedures, and Microeconomic Effects of Innovation," *Journal of Economic Literature*, vol. XXIV (September 1988), pp. 1120-1171.

34. Dr. Charles Bugg, a leading researcher in growing protein crystals in space, makes the point, "If a pharmaceutical company comes forward with a specific protein it would like to crystalize we really can't assign a probability that it will benefit [the company]." *Space News*, May 21-27, 1990, p. 10.

Figure 2.
Historical and Projected Funding for Commercial Programs



SOURCE: Congressional Budget Office based on data from the National Aeronautics and Space Administration.

gram is currently exploring the commercial potential of processing materials in microgravity.

The strategic role of the office is to act as a catalyst, disseminating information and drawing the private sector into space activities. Commercial promotion activity in the first instance encourages cooperation between private and public researchers and among private firms.[35]

35. An article by Lawrence J. DeLucas, Craig D. Smith, H. Wilson Smith, and others, "Protein Crystal Growth in Microgravity," *Science*, November 30, 1989, pp. 651-654, makes the point well when the

(Continued)

The program subsidizes commercial experiments in microgravity by providing technical support through exchanges of data and personnel with industry, access to government facilities at cost, free shuttle flights, and, in selected circumstances, deferred launch payments and/or exclusivity agreements. As a package, the set of incentives provides a pipeline running from the stage of initial interest to that of early experimentation or development, then to subsidized early operation, and finally to full commercial operation.[36] The dominant corporate interest to date has been on cooperation and information gathering, rather than on investment with specific products and processes in mind.

The most innovative activity of the office in institution-building is its support of 16 Centers for the Commercial Development of Space (CCDS). Each center draws together government, industry, and academia for the purpose of exploring potential commercial space activities. NASA provides partial funding support for each center, but the long-term objective of the program is full private funding. During 1986, NASA made awards of just under $8 million to the centers, that were matched by other contributions valued by NASA at slightly more than $8 million. By 1989, NASA was providing about $23 million in funding, while other contributions increased to almost $28 million.[37] The seven centers listed in Box 8 have materials processing in space as a primary interest. In 1989, they accounted for 57 percent of NASA funding to CCDSs and 66 percent of all outside CCDS funding from states, universities, and the private sector. Virtually all of the U.S.

35. Continued

institutional affiliations of the 24 coauthors of the article are considered. Seven of the 24 are from the University of Alabama and 4 from other universities. Two are from NASA's Marshall Space Flight Center. The remaining 11 are spread among 5 different private firms.

36. National Aeronautics and Space Administration, *NASA Commercial Programs: A Progress Report, 1988*, pp. 10 and 11, defines several of these incentives. The Technical Exchange Agreement provides for industrial participation in ground research. The Joint Endeavor Agreement (JEA) provides free transportation for experiments designed and funded by industry. The Space System Development Agreement (SSDA) permits deferred payments for early flights of commercial flight systems. Currently, eight firms have JEAs with NASA, and are developing flight experiments and equipment that they ultimately hope will contribute to their profitability. Four firms hold SSDAs that allow the private investor to defer payments to NASA for space transportation.

37. National Aeronautics and Space Administration, Office of Commercial Programs.

BOX 8
Centers for the Commercial Development of Space With Major Interests in Microgravity Materials Processing and Related Orbital Facilities

Center for Advanced Materials, Battelle Columbus Laboratories, Columbus, Ohio

Center for Development of Commercial Crystal Growth in Space, Center for Advanced Materials Processing, Clarkson University, Potsdam, New York

Consortium for Materials Development in Space, University of Alabama-Huntsville, Huntsville, Alabama

Center for Space Processing of Engineering Materials, Vanderbilt University, Nashville, Tennessee

Center for Macromolecular Crystallography, University of Alabama-Birmingham, Birmingham, Alabama

Center for Cell Research, Pennsylvania State University, University Park, Pennsylvania

Space Vacuum Epitaxy Center, Houston, Texas

firms interested in commercial space processing are currently affiliated with a CCDS, and the CCDSs fund most of the private-sector microgravity experiments.

The CCDS concept allows firms to learn about the prospects of processing materials in space at a relatively low cost, and provides an open door should the more enthusiastic claims about space processing prove true. The CCDS is an instance of the consortium idea that is being examined across a wide spectrum of technologies having commercial prospects.[38] The centers have been successful in drawing

38. Congressional Budget Office, *Using R&D Consortia for Commercial Innovation: SEMATECH, X-Ray Lithography, and High-Resolution Systems* (July 1990).

private interest and resources to space processing. Even if the program fails in its objective of creating financially self-sustaining entities, it could still serve a useful function in linking NASA to the private sector. Such links will be necessary in order to exploit the space station investment fully and to facilitate a two-way flow of information between NASA and the private sector.

Europe. Europe's effort to promote commercial involvement in microgravity processing of materials is led by Intospace, a European entity that includes participation by aerospace firms, potential industrial users, and private financial institutions.[39] Its function is to act as an intermediary between user industries and the public and private providers of microgravity experimental facilities. Like the CCDSs in the United States, it provides private users with free use of publicly supported orbital facilities for their experiments.[40] Intospace may have an advantage over its U.S. counterpart because it includes private financial institutions that, in theory at least, could help the European effort move forward if a solid prospect were to develop. Announcement has recently been made that a new organization, Columbus Space, will market the European space station's capacity to private users.

Japan. The Japanese effort also includes hybrid institutions that combine public and private funding. The Japan Space Utilization Promotion Center is led by MITI and the Science and Technology Agency. The government provided $2 million to the center in 1988, and 42 industrial companies contributed $5 million. The Space Technology Corporation, with start-up capital of under $2 million, includes major industrial corporations and government agencies. It is involved in preparing experiments for Japan's participation in the German Spacelab flight, D-2.[41] The Japanese government also provides favorable tax treatment--potentially applicable to materials processing--under the

39. *Commercial Space* (Fall 1985), pp. 28-29.

40. The West German Spacelab flights, D-2 and D-3, will reserve 30 percent of their experiment capacity for Intospace experiments. Currently, Intospace is also committed to experiments using a Chinese returnable carrier and others carried on board the Soviet space station MIR.

41. Euroconsult, E.C., *World Space Industry Survey: Ten Year Outlook 1988 Edition* (Paris, April 1988), pp. 333-336.

tax system for promoting basic technology, which grants a tax credit of 7 percent of the acquisition price (up to 15 percent of the corporate liability) on the purchase of very specific pieces of testing and research equipment.[42]

Commercial Crystallography: A Case Study

Of the prospects for commercial applications of the microgravity environment, none is currently drawing more private interest than protein crystallography. Growing crystals in space is of immediate interest as a support for ground-based crystal production. In the longer term, crystals may be among the first products to be profitably manufactured in space.[43]

The near-term potential demand for crystals grown in orbit comes from the pharmaceuticals, biotechnical, and chemicals industries. Crystals of biological or chemical materials are used in drug design, protein engineering, and the design of synthetic vaccines. A growing number of flight experiments have shown that crystals grown in space are larger and freer of defects than those produced on Earth.

The demand-side obstacles to greater investment in space-grown protein crystals are illustrated by the progress of processing materials in space in the pharmaceuticals industry. Crystallization of proteins is most useful to researchers pursuing a "rational approach" to drug design. The rational method of designing drugs involves analyzing the molecular structure of disease agents and developing pharmaceutical agents that penetrate the structure in a way analogous to a key fitting a lock. While rational design is promising, it is not the dominant approach to research in the pharmaceuticals industry.[44] The prevailing

42. "Space," *Science and Technology in Japan* (August 1987), p 22. While processing materials was listed as a general area of interest, specific test equipment did not appear on the list of allowed items as of 1987.

43. "Protein Crystals May Reveal Building Blocks of Life," *The New York Times*, March 3, 1989, p. C-1.

44. Yvonne Connoly Martin, Eberhard Kutter, and Volkhard Austel, ed., *Modern Drug Research: Paths to Better and Safer Drugs* (New York and Basel: Marcel Dekker, Inc., 1989), pp. vii-x, and Bert Spiker, *Multinational Drug Companies: Issues in Drug Discovery and Development* (New York: Raven Press, 1989), chap. 2.

pharmaceutical methodology is one of organized trial and error. Agent after agent is applied to a "screen"--a test organism, such as a rat--and by studying their effects the investigator selects prospects worth further examination. This well-established pattern of research practices limits the pool of researchers and research funds that might support microgravity experiments.

Even where crystallography is an accepted part of the design process, growing crystals in space is but one investment option. Other options are to grow crystals on Earth, model crystal structures on computers, or analyze crystal structures with specialized techniques such as magnetic resonance imaging. An increase in the pharmaceutical demand for space-grown crystals will come about, if it does, because investing in them compares favorably with the other options.

The role of the Centers for the Commercial Development of Space, and NASA's flight experiment incentives, is to tip the scale in favor of investments that explore the use of space-grown crystals. The Center for Macromolecular Crystallography at the University of Alabama at Birmingham has shown a degree of success in its efforts. NASA's contribution to the Center was $700,000 in 1988 and $1.5 million in 1989. The center was able to raise $6.8 million in 1988 and $7.2 million in 1989 from other sources.[45] From a federal perspective NASA's contribution was well leveraged, and the interim objective of generating private interest and support for space processing was accomplished.[46] Private contributors also perceived their contribution as leveraged. By participating in a center, the individual firm gains the information it needs to make investment choices at a relatively low cost.[47]

45. National Aeronautics and Space Administration, Office of Commercial Programs.

46. Federal funds that attract private funds to space processing should not be viewed as creating net new research and development investment. Funds directed toward the centers are best thought of as research funds that would have been spent in any case, but on different projects. One measure of the cost of the federal effort is the benefits of the research that would have been undertaken had the federal government not attempted to steer funds toward space processing. In the final analysis, the benefits generated by investment in space processing induced by federal policy must be sufficient to cover the cost of alternatives forgone.

47. Dr. Jack Knox, formerly of Amoco Chemicals, described Amoco's participation in one of the CCDSs as a way to gain access to a million dollars' worth of research for $25 thousand to $30 thousand. Jack Knox, "Commercialization of Space from a Nonaerospace Industry Viewpoint," Testimony before the Subcommittee on Science, Technology and Space, Senate Committee on Commerce, Science and Transportation, 101:2 (May 15, 1990).

While the results of these activities have been encouraging, they have not so far induced the industrial partners to increase their investment dramatically. But the center's researchers have generated a number of academic papers, and their flight experiments have been among the most successful in the U.S. program. In 1989 the center spun off its first private company, Biocyst. The company, capitalized by $5 million in local investment, applied for patents on six new protein crystals in 1990.[48]

POLICY OPTIONS

If the Congress chooses to alter the pace of the scientific and commercial exploration of microgravity, it could take a variety of different actions. In this case, the effects of public policy are best thought of as speeding up or slowing down a process of discovery with no certain end in sight. There is no way of telling whether the hope of substantial economic benefits will bear fruit.

Under current policy, the level of spending governs the pace of activity. Spending more or less on science, commercial promotion, and facilities should affect the rate at which discoveries are made. Choices are also open about whether to spend more on science or on commercial promotion, and whether or not to invest on the supply or demand side of the potential market.

The current program explicitly proclaims the scientific and commercial value of space processing, but concedes neither will be fully realized until the space station is operational toward the end of the 1990s. The implicit objective of the science program is to be ready for the space station with equipment and with an experiential base sufficient to make quick progress. The objective of the commercial promotion effort is different: to achieve enough research success to attract more private investment and interest in microgravity experimentation, leading to a profitable industry.

48. *Space News* (May 14-20, 1990), p. 2.

Increase Spending for Microgravity Activity. A 1987 report prepared for the NASA Administrator by an advisory task force recommended that spending on microgravity science and commercial programs be doubled and that flight opportunities be increased commensurately.[49] NASA has carried out these recommendations in spirit, if not in detail. As indicated in the review of supply conditions, science spending is on a strong upward trend: Spacelab missions are to be flown at a rate of approximately one a year over the next four years. Commercial payloads will be flown on the middeck of other shuttle missions when feasible, and will receive increased flight opportunities if the commercial middeck augmentation module and sounding rocket flights are funded.

The question of whether or not additional resources should be devoted to microgravity processing can be addressed in two dimensions: the cost of significantly expanding the national resource commitment, and its potential effect. Small increases in spending for scientific or commercial experiments are likely to be restricted to the budgets for processing materials in space and commercial programs. This is because marginal changes in the level of microgravity activity can be accommodated within the current operational and transportation infrastructure. Significant increases in activities in microgravity space processing of the size made since 1987 could require proportionably larger spending increases or decreases in other science activities as the operational and transportation infrastructure was pushed closer to full capacity.

The availability of shuttle flights may prove to be the factor limiting increased microgravity activity. If so, it may be preferable to expand activity in the commercial rather than the scientific program. Commercial experiments are usually smaller in scale than those generated by the science program. They can be more easily integrated as secondary payloads on shuttle flights that do not have microgravity as their primary mission. The Commercial Middeck Augmentation Module will make this type of opportunity more available. Commercial experiments are also more likely to use facilities other than the

49. National Aeronautics and Space Administration, *Microgravity Materials Science Assessment Task Force--Final Report* (1987).

shuttle, and are thus not as constrained by the shuttle flight schedule. Both expanding the COMET program and permitting U.S.-supported experiments to fly on the Soviet space station MIR would provide access to microgravity independent of the shuttle system.

Increased spending to support commercially developed experiments would, unlike spending in the science program, be independent of the space station program. Moreover, expansion of the commercial experimental budget could be keyed to success in experimental activities that have already been funded, and to the willingness of private experimenters to contribute resources, rather than to hopes for the space station.

Decrease Funding for Microgravity Activity. Should the Congress wish to decrease funding for microgravity science and commercial promotion, the science program's larger budget and operational requirement offers the most likely target. Savings could be achieved in the science program by canceling or deferring the development of major experimental facilities and equipment. Shuttle missions carrying major microgravity payloads could be canceled, saving the marginal cost of each flight as well as the cost of developing experiments and equipment. Cuts in the science program would delay productive use of the space station--if, in fact, space processing turns out to be a productive use--but a significant slippage in the schedule of the space station program would make this consideration less important.

Even after Congressional acceptance of NASA's 1991 budget request that more than doubled the commercial program's budget, canceling the entire program would save only $76 million annually.

Eliminating the commercial support budget would reverse the policy of the last 10 years, based on the belief that microgravity experimentation could yield at least some economic benefits. Choosing not to grant increased funding for orbital facilities would slow the rate of progress in commercial applications and discourage new corporate interest in microgravity experimentation. Since a concern over U.S. competitiveness underlies the policy of encouraging private investment in space processing, eliminating the commercial support budget would raise this issue again. But the question remains whether or not microgravity materials processing in space has commercial value to begin with. Falling behind in a race without a finish line or a prize would be of little consequence.