A Herculean Task? Economics, Politics, and Realigning Government in the Case of U.S. Polar-Orbiting Weather Satellites

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Abstract

In 1994 one of the most radical institutional restructurings in the U.S. government's provision of critical weather information took place after eight unsuccessful attempts. A presidential decision directive merged weather data collection by satellites operated by the Department of Defense for military operations and satellites operated by the Department of Commerce for civilian weather forecasting. Such radical restructuring involving government agencies with different objectives, economic constraints, and operating cultures is rare. This paper reviews the decision that led to "convergence," discusses economic arguments advanced for the merger, and finds that the problem of an incomplete contract, from the perspective of contract theory, is the fundamental challenge confronting the new structure. The paper also discusses the implications of the new organizational structure for incentives to engage in research and development in pushing the frontier of space technology, and the increasingly large role played by satellites in collecting not only weather but also climate-related data.

Key Words: weather economics, space economics, value of information, government policy

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A Herculean Task? Economics, Politics, and Realigning Government in the Case of U.S. Polar-Orbiting Weather Satellites

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1. Introduction

In 1994, one of the most radical restructurings in the U.S. government's provision of critical weather and related information services took place. After eight previous but unsuccessful attempts, a presidential directive in May 1994 led to the merger of crucial parts of the nation's civilian and military weather data collection satellite systems. The merger was intended to reduce overlap in the systems and ultimately save money.

Most observers find that the new, jointly operated system, the National Polar-Orbiting Operational Environmental Satellite System (NPOESS), is functioning well except for a problem that plagues almost every federal program—budgetary shortfalls. These shortfalls loom large for NPOESS particularly because the satellites that are to be built and operated under the new program are only now being scheduled; the planned data-collection capability of the new system is expanding rapidly to encompass not just weather but also observations to support research on global climate phenomena; international participation, on which some cost savings expectations are based, is uncertain; and the data-processing capacity, which will be some 10 times larger than current capability, requires significant expansion and upgrades. In addition, this long-lived program must keep up with technological developments in data collection instruments and related space technologies, but at the same time balance the risks of using innovative technology with the requirement to provide reliable, fail-safe, routinely operating weather data collection.

This paper reviews the background of the merger that formed NPOESS, its status, and the challenges now confronting the program. The paper also addresses some "value of information" approaches to improved understanding of the benefits of data from NPOESS. The value of

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information discussion is pertinent because the merger itself focused on cost savings, but however attractive, saving money alone does not go far in informing decisionmakers about the usefulness of bits and bytes.

The paper begins with a description of polar-orbiting satellites and the customers for their data, including researchers' rapidly expanding demand for data about changes in climate. This introductory section also reviews the current status of federal funding of the new program. The paper then offers background about the decision to form the new joint program, including discussion about the anticipated cost savings. The next sections discuss the status of the program and challenges that figure prominently, as well as possible ways to help fix some of the problems that NPOESS is encountering.

1.1. The satellite systems and their customers

For nearly four decades the United States has operated separate but quite similar civil and military polar-orbiting environmental satellite systems. The systems collect, process, and distribute remotely sensed meteorological, oceanographic, and space environmental data. The National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce (DoC) and the U.S. Department of Defense (DoD) operate the systems.

Since the 1960s, NOAA has been responsible for the Polar-Orbiting Environmental Satellite system (POES). Unlike familiar geostationary satellites, which maintain a fixed position above the earth, POES spacecraft operate about 500 to 600 miles above the earth in circular, near-polar (that is, almost north-south), sun-synchronous orbits. The POES system uses two satellites, each of which views almost all the earth's surface about twice daily. One satellite passes over the equator at 10:00 a.m. and the other at 1:30 p.m. (local time) each day. The instruments on the satellites scan an area about 1,800 miles wide and detect environmental measures either reflected or emitted from the earth, the atmosphere, and space. Ground stations in some 120 nations receive POES weather data.

Meteorologists in the public and private sectors, in the United States and abroad, use POES data primarily for weather prediction. Some 96% of the data used to initialize the forecasts of their models comes from POES platforms. Forecasters also routinely combine POES data with data from other sources, such as geostationary satellites, radar, weather balloons, and surface observing systems. In the absence of POES data, forecasts would probably be accurate for one to two days at most; longer outlooks of three to seven days would not be possible.

The Department of Defense began the Defense Meteorological Satellite Program (DMSP) in 1965 and has since deployed a series of more than 40 satellites. Two DMSP satellites operate in orbits similar to that of the POES system but pass over the equator at 5:30 a.m. and 7:30 p.m. Together with the two POES satellites, all four satellites provide weather data that are generally no more than six hours old. The Air Force operates satellite command-and-control facilities for DMSP.

DMSP supports national security requirements, including identification, location, and determination of the intensity of severe weather. The program also assists in search-and-rescue operations. Many of the additional DoD uses of DMSP data are unique to military operations. For instance, wind and temperature forecasts based on DMSP measurements support decisions to launch aircraft that need midflight refueling. DMSP also measures local charged particles and electromagnetic fields to assess the impact of the ionosphere on ballistic-missile early warning radar systems and long-range communications. Additionally, the data help in monitoring global auroral activity and predicting the effects of the environment of space on military satellite operations. DMSP stores some of the data it collects but also transmits some data in real time to field terminals that are in a direct line of sight of the satellites. Field terminals can be taken into areas with little data communications infrastructure, such as on a battlefield or a ship.

DMSP also provides civilian meteorologists with data on global weather. The system's nighttime passes use the visible near-infrared spectral band to detect faint sources of emissions from city lights and fires. This light detection capability of DMSP allows its use for near-real-time global monitoring of fires.

1.2. "Convergence" and an increasing focus on climate data

Presidential Decision Directive/NSTC-2, signed by President Clinton in May 1994, directed DoD, DoC, and the National Aeronautics and Space Administration (NASA) to establish a joint, or converged, national polar-orbiting weather satellite program. The new program, the National Polar-orbiting Operational Environmental Satellite System (NPOESS), combines the DMSP and POES services into a single coordinated system of satellites. According to NOAA, the merger of these programs is the most significant change in U.S. operational use of space for environmental purposes since the launch of the first weather satellite in 1960.[1]

In the decade since establishment of NPOESS, the potential applications of satellite data for research on global climate change have developed rapidly. At present NPOESS is intended to supply a large array of data that extend beyond weather-related measurements. Table 1 lists 13 instruments that were planned for NPOESS satellites as of July 2002 and describes many of the applications to be supported by data from these instruments.

1.3. Funding

The NPOESS program office estimates that the system will cost about $6.5 billion (in today's dollars) over the 24-year period from inception of the program in 1995 through 2018. This funding is to provide launch vehicles, satellites and sensors, data-processing hardware and software, and command, control, and communications for system operations. The first satellite is scheduled for delivery in 2008 and will be launched either that year, if necessary to back up the last POES spacecraft, or in 2009. The second NPOESS satellite is set for launch in 2009, if needed to back up the last DMSP satellite, or in 2011. Subsequent launches of four more satellites, for a total of six in the program, are to occur about every two years through 2018.

Table 2 outlines NPOESS funding for fiscal year 2001 to "cost to complete" and also notes funding spent prior to 2001. As an example of how funds are allocated on a yearly basis, the fiscal year 2001 funds from DoD are to support the NPOESS program office ($643,000), complete system architecture studies and definition ($24,800,000), and continue sensor and algorithm development and sensor design and fabrication ($45,589,000).

Not reflected in the table are expenditures by NASA for its research and development contribution to NPOESS. Data for fiscal year 2004 show that the space agency has requested about $96 million for its NPOESS-related activity.[2]

To provide context for the size of NPOESS on annual budget basis, Table 3 shows the administration's fiscal year 2003 plan for *all* U.S. government meteorological services and

[1] See "The National Polar-Orbiting Operational Environmental Satellite System (NPOESS)" at http://www.publicaffairs.noaa.gov/grounders/npoess.html (accessed May 2003).

[2] See National Aeronautics and Space Administration "Summary of FY 2004 Budget Request" at http://www.nasa.gov (accessed May 2003).

supporting research (not only NPOESS) and the allocation of these funds among all agencies involved in these services. For fiscal year 2003, the president proposed total operations of about $2.5 billion and supporting research of about $380 million. About 75%, or about $2 billion, of all of the meteorological operating funds goes to DoC and DoD. The budget for NASA to provide supporting research is about $154 million and accounts for the major share of supporting research (about 40%). Some 14,460 full-time-equivalent government personnel are involved in the entire sector. NPOESS is not the largest of the programs within this overall annual federal meteorological services budget, but with a fiscal year 2003 budget of about $500 million, NPOESS represents a fairly large share—about 20%.

1.4. Contract awards

At this stage of NPOESS development, an increasingly large portion of the NPOESS budget is allocated to building and designing instruments. For example, contracts have been awarded to Ball Aerospace and Technologies Corporation of Boulder, Colorado, for the development and fabrication of instruments to measure ozone; to ITT Industries of Fort Wayne, Indiana, for measurement of temperature and moisture in the atmosphere; and to Saab Ericsson Space of Goteborg, Sweden, for an instrument to measure tropospheric temperature and humidity profiles. Other contractors include the Raytheon Corporation of Santa Barbara, California, for instruments to measure atmospheric, oceanic, and terrestrial parameters, and the Boeing Company of El Segundo, California, for microwave measurements of ocean surface wind speed, sea surface temperature, and cloud moisture content. The Ball Aerospace Corporation has a contract to design and build a spacecraft bus and integrate government-furnished instruments in preparation for future incorporation in NPOESS spacecraft.

In summer 2002 NPOESS awarded the largest contract in the program to date. This contract provides for design, construction, and deployment of the NPOESS spacecraft and was awarded to the TRW Company (which was acquired by Northrup Grumman in fall 2002). The contract includes $2.8 billion for two satellites, with options for four additional satellites, bringing the total potential value to $4.5 billion.

For perspective, the amount of funding for two NPOESS satellites ($2.8 billion) is considerably more than the expenditure planned for the U.S. global climate change research program in fiscal year 2003 (about $1.7 billion). The contract plus the options for additional satellites (totaling $4.5 billion) is about a third of the nation's annual space budget.

2. Impetus for change

Before the creation of NPOESS in 1994, government officials had considered the possibility of combining the POES and DMSP systems eight times. The rationale in each case was the same—that there might be unnecessary redundancy in their operation along with extra expense, and that greater operating efficiency might be obtained from a combined system.

The two programs had always cooperated to some extent, but fundamental differences in the service requirements of DoD and NOAA had prevented a merger. Neither agency wanted to relinquish its program to joint management, and equally important, the agencies used different protocols for distributing data. NOAA routinely shared data at no or low cost not only with U.S. meteorologists but also with weather agencies around the world. DoD produced weather data almost exclusively for its own operational requirements. The civilian POES program had a long history of international cooperation in sharing data, a practice that was anathema to DMSP. DMSP primarily served operational requirements for DoD while the POES program included data collection for purposes of science research. Upholding these research commitments under a merged program was a basic concern of NOAA and civilian weather researchers, and the preservation and enhancement of national security was important to DoD. For these reasons, appropriately balancing and accommodating all policy objectives was a stumbling block in the early attempts to join the two programs.

2.1. The 1994 decision

In the early 1990s, the Clinton administration sponsored a national performance review of all U.S. government operations. The review found that establishing a single civilian operational environmental polar satellite program would "reduce duplication and save taxpayers a billion dollars over the next decade."[3] Congress also drafted the Government Reinvention Act (H.R. 3400), which included a provision authorizing a merger of the two systems. The new joint program was to satisfy both civilian and national security requirements. President Clinton signed the "Space Technology Council Presidential Decision Directive, Convergence of U.S. Polar Operational Environmental Satellite Systems" establishing NPOESS in 1994.

[3] See "From Red Tape to Results: Creating a Government that Works Better and Costs Less—Report of the National Performance Review" at http:/acts.poly.edu/cd/npr/np-realtoc.html (accessed May 2003).

According to D. James Baker, then administrator of NOAA, the "clincher" for convergence on this ninth try were budgetary considerations as well as the support of influential leadership at NOAA and DoD and in the White House. In addition, leaders in Congress agreed that it was time to operate the programs jointly. Baker emphasizes this factor by citing it as one of the most important "lessons learned" from his experience as administrator in effecting change.[4]

DoD, DoC, and NASA formed a triagency Integrated Program Office (IPO) for NPOESS on October 1, 1994, to manage the converged system. The IPO administers the program, and an executive committee consisting of the DoD undersecretary of the Air Force, the NOAA undersecretary for Oceans and Atmosphere, and the deputy administrator of NASA oversees the program. DoC through NOAA is responsible for overall management and for coordination with national and international civilian users and also ensures that these activities are consistent with national security and foreign policy requirements. DoD is responsible for acquiring the NPOESS systems. NASA supports development of new instruments and other technologies for use by NPOESS.

2.2. Expected cost savings

Advocates of the merger estimated that joint operation of the systems would save taxpayers up to $300 million during the first few years (1995 through 1999) with additional savings of $1 billion or more over the 10-year life of the program.[5] NOAA reports that savings are to accrue in several areas, including fixed costs of administration and management, variable costs of daily operations, and long-run costs of investment in new capacity. NOAA specifically cites these categories of potential cost reductions but does not provide amounts by category[6]:

- *Development.* Only one development effort is required for NPOESS rather than two efforts for designing independent systems of spacecraft, instruments, and ground command-and-control.

[4] Baker (2002).

[5] See http://www.publicaffairs.noaa.gov/pr95/jun95/converge.html (accessed May 2003).

[6] See http://www.publicaffairs.noaa.gov/grounders/npoess.html (accessed May 2003).

- *Satellites and launches.* The previously planned DMPS and POES programs were expected to require 3 U.S. satellites in operation at a time, each with a design life of about 4 years, and 11 satellites were to be procured and launched over the 10-year life of the programs. Although NPOESS will similarly require 3 U.S. satellites in operation at a time, their longer design life—5 to 6 years of operation—means that only 6 satellites will have to be procured and launched over the 10 years of the program.
- *Ground systems, operations, and management.* Consolidating the DMSP and POES operations and halving the number of government management staff and contractors are expected to reduce costs.
- *International cooperation.* Additional savings are expected through international cooperation in sharing satellite data and perhaps ground operations.
- *Capability.* The program may provide synergies as different types of data are combined in new ways for improved forecasting and other environmental monitoring services.

Taken together, those items suggest the potential for at least two sources of expected savings. One is economies of scale, in which costs are saved by sharing management and facilities. The other is economies of scope, in which synergies create different types of data products than would otherwise be available.

Another important provision of the new program is that NASA, in conjunction with its series of earth-observing satellites, is to develop and test new data collection instruments and other space technologies on behalf of the program. Once NASA has “flight-validated” the new technologies, they would be made available to NPOESS. With NASA’s involvement, NPOESS could incorporate new, state-of-the-art devices with much less risk of failure or threat to NPOESS regular operations. Although this provision is not identified as a direct savings in cost, the NASA role in validating new technology is seen as helpful in reducing technological and programmatic risks (and the costs of possible failure) associated with flying new instruments in space. Reducing risks can have the benefits of avoiding direct financial costs of failure as well as alleged political costs of failure when new space technologies go awry.

3. Status

As of 2003, convergence of DMPS and POES had not been completed, largely because NPOESS spacecraft have yet to be constructed. The initial operating plan concluded that current satellites then under construction for DMSP and POES could not be significantly redesigned without intolerable cost overruns. Even though DMSP and POES are similar, their satellites carry some distinctly different hardware and serve different mission requirements. As a result, the program is still "flying out" the pipeline of DMSP and POES spacecraft that were planned before convergence.

3.1. The infusion of new technology

From its Earth Science Enterprise division, NASA is carrying out its bridging role between the current generation of spacecraft—its earth-observing satellites as well as DMSP and POES—and the new NPOESS spacecraft under the NPOESS Preparatory Program (NPP). NPP is a spacecraft to be launched in 2005 or 2006 to test advanced ground operations facilities and validate sensors and algorithms while today's operational DMSP and POES systems are still in place. As currently planned, the NPP will have three sensors to measure clouds, greenhouse gases, sea surface temperatures, land and ocean biological productivity, and ozone. A particularly important contribution of NPP is that it is expected to replicate about 80% of the NPOESS data-processing load. As a prelude to NPP, two recently launched spacecraft, dubbed Terra and Aqua, carry new instruments that may later be used by NPOESS.[7]

Much of the NPOESS documentation emphasizes "substantial risk reduction" as a goal of the program.[8] Risk reduction is to be carried out largely by testing instruments on the ground and on aircraft before they are flown in space and by deferring major acquisition decisions "as long as reasonable" to keep up with new technology. The delicate balance of infusing new technology to ensure that NPOESS is adequately state-of-the-art while not jeopardizing the program's

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[7] The original names of these spacecraft—"EOS-AM" (Terra) and "EOS-PM" (Aqua)—are worth noting because a large reference and background literature uses the original designations. Additional information about NPP is at http://www.jointmission.gsfc.nasa.gov/science.html (accessed May 2003).

[8] The NPOESS program Web site includes discussion of the approach to technical risk reduction. See http://www.ipo.noaa/gov/Projects/HeritageAndRiskReduction.html (accessed May 2003). See also discussion in U.S. Congress, General Accounting Office (2002).

requirement to provide a reliable supply of weather data is at the heart of maintaining a long-lived technology program.

3.2. Climate research and NPOESS

An additional role for NPOESS—that of collecting data to support research on global climate—has also evolved significantly since the merger of DMSP and POES began. A detailed study by the National Academy of Sciences emphasizes that NPOESS data could support not only weather forecasting but also, if new instruments were appropriately calibrated and data were archived, the examination of long-term trends in climate processes (see National Research Council 2000). The NPOESS data could supply a large array of measurements of atmosphere, oceans, land, and the space environment. The National Academy of Sciences also urges that NPP become more than a "one-time" opportunity to bridge the technology gap between POES-DMSP and NPOESS. It recommends that NPP become a permanent centerpiece for maintaining state-of-the-art data collection to facilitate the role of NPOESS data in climate research.

3.3. Data management

Because the data flow from NPOESS spacecraft will be large, Congress and the General Accounting Office (the investigative arm of Congress) have asked NOAA to develop and implement plans to deal with managing these data. Whereas current polar-orbiting satellites produce about 10 gigabytes of data per day, NPOESS is expected to supply 10 times that amount. Among specific concerns are having adequate network bandwidth to receive data at ground stations, capacity and algorithms for validating and verifying the quality of the data, protocols for distributing the data, and procedures and capacity for archiving them. The NPOESS data-processing centers report that their current infrastructure (the computational power of their supercomputers, communications systems to transmit the data, and storage facilities for data archiving) will not be able to handle all the anticipated data.[9] Some centers state that they could support virtually none of it at the rate at which it will be arriving from the satellites.

At present, IPO has satellite control authority over the DMSP spacecraft but not over POES spacecraft, which are still operated by NOAA. Several more DMSP and POES spacecraft, already contracted and built, will be launched to maintain the existing constellation of two

[9] See U.S. Congress, General Accounting Office (2002).

primary DMSP and two primary POES spacecraft until NPOESS spacecraft become available, around 2008. Although the primary command-and-control facilities and data distribution center for both systems have been centralized in Suitland, Maryland, organizational structures are still evolving, with program management of POES and DMSP split between two offices (management will eventually move to one office under NPOESS).

3.4. Cost savings

Tracking the actual cost savings under NPOESS to date and calculating potential future savings are difficult. Historical cost data are incomplete and inconsistently reported, with different formats, cost categories, and timing of expenditures. The amount of future savings is also unclear because the scale and scope of the program are changing based on research and development, the vagaries of international cooperation, and the shifting priorities of federal budgets. The counterfactual data to show what POES and DMSP would have cost in the absence of NPOESS during future years are also missing.

Subject to those considerable limitations, NOAA reports that to date, NPOESS has provided more than $670 million in savings through fiscal year 2001 and is expected to save about $1.6 billion more compared with the costs of continuing the previously planned upgrades to the separate satellite systems within DoD and DoC. NOAA also reports that NPOESS saved about $50 million in operational costs during the first two years of the program, and reductions in staff have saved about $8 million a year compared with costs that would have been incurred under separate POES and DMSP systems.

Some expected cost savings are probably in doubt. For example, it is not clear whether the potentially significant extra expenditures for improving data management capability and capacity are fully known or yet reflected in the NPOESS budget data or projected cost savings. In addition, the European Union (EU) Europe changed its plans and decided not to build and fly a spacecraft that would support NPOESS. Instead, NOAA and Eumetsat are discussing compatibility in the technical operation and data collection systems of the EU's existing series of Metop polar-orbiting weather satellites and NPOESS. Decisions about some of the instruments that would be flown by NPOESS, such as a scatterometer to measure surface winds, depend on the EU's decisions, thus keeping final plans for instrumentation of NPOESS in flux. Some additional international participation is under way, however, including an agreement with the Norwegian Space Center for high-latitude satellite tracking and data acquisition. As of 2002, discussions were ongoing with Japan on concepts of cooperative operations for ground stations.

A possible concern to be resolved in all of these international arrangements, however, is whether DoD's involvement with NPOESS could present difficulties in the form of restrictions on sharing data widely among different countries or during times of international conflict. [10]

4. An effective merger?

NPOESS is still a work in progress. Its management structure seems well designed, but factors somewhat external to management, including intricacies of the federal budget process, loom large.

4.1. Management design

In their study of the formation of NPOESS, Johnson et al. (2001) list these reasons for establishing joint programs such as NPOESS:

- improving interoperability among components and reducing duplication;
- reducing development and production costs;
- meeting similar interagency service requirements; and
- reducing logistics requirements through standardization.

To achieve those goals, approaches to interagency cooperation range from formally establishing a joint or integrated program office (like the IPO for NPOESS) to creating a wholly new agency, to merely appointing an "executing agent"—that is, designating one agency to lead technology demonstration, development, acquisition, and/or operation of the program.

Johnson et al. find that NPOESS as designed seems positioned to meet the goals for several reasons. A memorandum of agreement (MOA) signed by all three agencies in 1995 gives each agency representation in the IPO, locates personnel in a central office, and directs integration to take place over several years, thus allowing time for solving problems. The MOA designated NOAA as the lead agency, with charge of operations and the international interface. DoD, with its significant acquisition experience, was assigned acquisition responsibility, easing the agency's concerns about whether future systems would meet DoD requirements.

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[10] See http://www.publicaffairs. noaa.gov/grounders/npoess.html; Taverna (2002); http://www.ipo.noaa.gov/About/partners.html; and http://www.ceos.esa.int/plenary16/agencyreports/agencyreport_noaa.doc (Web sites accessed May 2003).

4.2. Challenges of implementation

Much of the challenge has come with implementation. The presidential decision directive establishing NPOESS stated the goal of an effective merger, and the subsequent program design—the MOA and the IPO—set up the formal NPOESS structure. These "articles of incorporation" were nonetheless incomplete, by necessity: they have been inadequate for enforcing an effective bargaining relationship after reorganization.

4.2.1. The "contract" and funding

The MOA has been inadequate as a formal mechanism to govern the joint venture. Two important ingredients of a contract—whether between companies, individuals, or institutions in the private sector, from real estate to corporate mergers—are "who pays" and "how much." Such contracts also include provisions for enforcement and penalties for withdrawal. The MOA for NPOESS discusses who pays and how much, but actual funding of NPOESS is left to the federal budget process. For this reason, the MOA is incomplete as a contract: it lacks enforcement and penalties.

The MOA outlines how the program will operate, assets will be merged, and responsibilities will be delegated. It states that all "near-term common activities" are to be funded by DoD and DoC by dividing the budget 50-50 and presents a 50-50 cost-splitting budget profile for fiscal years 1996 through 2001. The MOA also stipulates conditions under which the agencies would not split costs 50-50. Cost sharing is to be reassessed at a minimum prior to each acquisition milestone review, thus opening up the possibility of a different division of costs. In addition, "unique agency requirements" will be funded by the appropriate agency, and if an agency's more stringent requirements for common data products are determined to be a significant cost driver, then the additional funds required will be provided by this agency. (Since NASA is not an operational agency, its contribution to NPOESS is by way of supplying NASA-funded instruments for flight on the NPOESS platform at no unit cost to the NPOESS program. The policy of supplying instruments at no cost will apply as long as NASA continues to need the data supplied by the instrument to fulfill its primary research mission objectives.)

Despite its attention to details about who pays, the MOA cannot compel any actual commitment of agency resources. The MOA cannot mandate the size of budgets or specify and enforce the exact manner and timelines for operation of a fully converged system. Maintaining required funding has been the largest and most continuous problem in implementing NPOESS. Following the presidential directive establishing NPOESS, the program had sufficient support in the agencies and in Congress to carry an adequate budget for a few years. But subsequent years have brought significant budget cuts.

4.2.2. The budget process

Perhaps one of the biggest stumbling blocks in NPOESS funding involves differences in the budget planning cycles among partners. An integrated program requires more effort to maintain funding levels, for several reasons.

Asymmetry in importance. Partner agencies may ascribe different levels of importance to the project and as a result disagree about each agency's financial contribution. Like any large program with funding spread out over many years, NPOESS is constantly subject to budget cuts within discretionary funding debates. As one observer commented, NPOESS is NOAA's carrier battle group—a really large, highly visible project for NOAA, representing some 15% to 20% of the agency's some $3 billion budget. Within DoD, however, NPOESS is a small part of even the DoD space budget and not a top priority among most Pentagon leaders. NPOESS competes with a wide range of DoD programs and is an easy target for cuts to pay for military equipment. As a result, in fiscal year 2003 DoD reduced planned NPOESS spending by some $50 million. Because the cost share is 50-50, such cuts imply a smaller NOAA contribution for NPOESS and would result in a smaller NPOESS budget overall.

Difficulties in coordination and negotiation. The costs of maintaining support among legislative and departmental bodies with distinct political, mission, programmatic, and budgetary priorities can be large. Managing the budget within two (or three, if NASA is included) separate agencies compounds the difficulty because managers must argue their priorities within three bureaucracies, each operating on a different budget cycle (and thus information is due to comptrollers at different times of the fiscal year). The DoD budget cycle begins a few months before that of DoC, for example.

Support for the converged program must also be won from pivotal members of the multiple congressional committees that influence the program, including leaders in the House and Senate Authorization and Appropriations committees, both on the Defense and the Commerce committees. If either department receives a lower budget than requested, the 50-50 mandate tends to drive both contributions to the lower rather than the higher number. In addition, it takes time and resources to brief budget examiners at the Office of Management and Budget (OMB) and at the Office of Science and Technology Policy and thus maintain executive-branch support. The IPO considers OMB to be a place for resolving disputes, but even within OMB, NPOESS must coordinate with three separate auditors—for DoD, DoC, and NASA. The IPO estimates that keeping the full complement of funding decisionmakers informed consumes about 80% of its time.

R&D and technology infusion. Another challenge with implications for funding arises from attempts to take advantage of new technology, but not at the risk of harming the operational reliability of the system. The nature of research and development and the rate of its incorporation can be a source of disagreement, and government programs that seek to balance system operations and research tend to be conservative in their adoption of new technology. Failure—of entire systems or even a single instrument—can be expensive in loss of data, replacement costs, and the political and investigative inquiry that attends high-cost or highly visible programs. A related and long-standing controversy in space research has been the extent to which technological risk should be incorporated into space missions. Mission planners seek to balance the mix of state-of-the-art and flight-proven technology in spacecraft design. The more untested the technology, both in ground testing and in the harsh environment of space launch and operation, the greater the risk of technological failure. Most critics agree that the balance tends to be tilted heavily toward proven technology rather than the infusion of advanced technology because planners are averse to taking a risk in flying brand-new technology: the programmatic and political costs can be too large.

Political capital from the private sector. Another concern involves the costs that private industry incurs in bidding to build follow-on instruments and spacecraft. The issue here is not only the actual costs of preparing the bid but also the extent to which companies expend lobbying and other efforts to influence the selection process. With consolidation of the two systems into one, will companies work even harder to win the sole contract? The costs involved when resources are expended on lobbying efforts are borne by society as a whole, through the shareholders of the companies. After the NPOESS contract award to TRW (which competed against Lockheed), industry financial analysts spoke of the federal government's "desire to keep its defense contractors healthy."[11] Regardless of the interpretation given to the relationship between government and contractors, the bidding process, in which both parties play a negotiating role, directly affects the funding outcome.

Mediating requirements. Defining and measuring customer requirements—which data and how much to collect and disseminate—are decisions that determine instrumentation and

[11] See Hamm (2002).

influence operations and funding for NPOESS. The problem of mediating requirements is long-standing and ubiquitous among a host of government programs.

An interesting approach—and one that might prove useful in management of NPOESS—was taken by NASA's Jet Propulsion Laboratory in the 1970s (see Raiffa 1982). The lab faced a dispute among aerospace scientists over the selection of trajectories for the two Voyager probes (originally named Mariner) to Jupiter and Saturn. The trajectories were important because they would significantly affect the nature of the science investigations. To resolve the dispute, the lab divided the approximately 80 scientists who wanted to use data from the probes into 10 teams to help select the pair of trajectories. The teams first articulated their preferences by stating the trajectories each would most like to have, then they were asked to rank all the suggested responses and indicate the relative strengths of the preferences by means of a cardinal utility scale (the worst pair would get a score of zero and the best a score of 1.0). If a given team scored a particular pair with a value of .73, this could be interpreted to mean that the team evaluated getting that pair for sure as equally desirable to getting a chance of .73 at their best alternative and a chance of .27 at their worst alternative. The process involved some additional steps, but in short, it led to selection of trajectories deemed most useful to most of the scientists. Moreover, in follow-up interviews about the voting process, the scientists "felt overwhelmingly that the process was fair" and that ranking had furthered understanding and communication among the teams and with management. But they also viewed the process with some skepticism because they suspected that some teams strategically "gamed" their votes.

The value of NPOESS data. The failure to measure data requirements is largely related to the problem of defining and measuring the value of information—a problem that has plagued the Landsat program and other space-based remote-sensing activities. Observers have emphasized that part of the problem leading to cuts by DoD has been the need to realize the benefits of the data.

More generally, this problem characterizes the nonmarket nature of the goods and services provided by government (for a good discussion, see Mueller 1989). Agencies typically supply not a number of units of output as such, but levels of activities. For instance, DoD maintains numbers of combat personnel and weapon systems, although it supplies various degrees (units) of defensive and offensive capabilities. Its budget is defined over the activities it maintains, even though the purchasers—the taxpayers and their representatives—are ultimately interested only in the final "outputs" of combat capabilities that these activities produce.

The measurement problem is thus inherent in the provision of weather and climate services. This issue has historically complicated funding decisions for weather services (for just a few examples from the past decade or so, see U.S. Congress, General Accounting Office 1989 and 1991). Measurable units of inputs include spacecraft, instruments, staffing, and operations costs. Units of output—that is, the value of the information gleaned from data, beyond merely counting bytes of data or numbers of weather "products" supplied—are more difficult to measure. Given the unmeasurable nature of government outputs, how can taxpayers and their representatives monitor the efficiency of their production?

This problem is intensified by the bilateral monopoly nature of the agencies and their stakeholder relationship. DoD and the weather services are agents: they are buying an NPOESS system on behalf of the taxpaying public. But DoD and NOAA are at the same time supplying the system, and thus serving as both buyer and seller. This relationship complicates the oversight job of OMB and Congress in their attempts to determine the right level of funding for NPOESS, and it influences the government and contractor negotiations noted above.

A large literature considers how to assess the value of information in general and of some specific types of weather information in particular. A rigorous and consistent application of the methodology described in that literature has never been given to space remote-sensing activities, however, or to specific activities like NPOESS. As a result, it is difficult to determine the extent to which NPOESS funding is too small, too large, or "just right."

Because a gap in understanding the potential value of NPOESS information complicates effective program funding, Box 1 illustrates some of the basics of value of information that could be applied to future study of NPOESS. Appendix A offers further discussion of approaches to measuring the value of information (see Macauley 1997 and its references).

The problem of funding confronts all government programs. NPOESS is no different, but its status as a jointly operated, technology-based program supplying a difficult-to-value information commodity contributes to the problem. Despite the challenges, NPOESS has a strong management basis upon which to build: the IPO structure seems sound.

5. Conclusions

Proof of the success of NPOESS is in the pudding—and the recipe and ingredients are still under assembly. As the NPOESS spacecraft are built and launched, the potential of NPOESS to bring cost-effective, state-of-the-art weather and climate information to a wide community of customers will come closer to realization. Data management for both infrastructure and international sharing, the infusion of appropriate new technology at an appropriate rate, and adequate funding are among the issues. Improving understanding of just how much the NPOESS data are worth involves a value question common to almost all government services. Future research about the value of NPOESS data could go far in winning support for the program by improving understanding of this "benefit" side of the cost calculus.

Table 1: Planned NPOESS instruments

Instrument	*Description*
Advanced technology microwave sounder	Measures microwave energy released and scattered by the atmosphere; used with infrared sounding data from the NPOESS cross-track infrared sounder to produce daily global atmospheric temperature, humidity, and pressure profiles
Aerosol polarimetry sensor	Retrieves specific aerosol (liquid droplets or solid particles suspended in the atmosphere, such as sea spray, smog, and smoke) and cloud measurements
Conical microwave imager-sounder	Collects microwave images and data to measure rain rate, ocean surface wind speed and direction, amount of water in clouds, soil moisture, and temperature and humidity at different atmospheric levels
Cross-track infrared sounder	Measures earth's radiation to determine the vertical distribution of temperature, moisture, and pressure in the atmosphere
Data collection system	Collects environmental data from platforms around the world and delivers them to users worldwide
Earth radiation budget sensor	Measures solar shortwave radiation and long-wave radiation released by the earth back into space on a worldwide scale to enhance long-term climate studies
Global positioning system occultation sensor	Measures the refraction of radio wave signals from the global positioning system and Russia's global navigation satellite system to characterize the ionosphere
Ozone mapper-profiler suite	Collects data to measure the amount and distribution of ozone in the earth's atmosphere
Radar altimeter	Measures variances in sea surface height and topography and ocean surface roughness to determine sea surface height, significant wave height, and ocean surface wind speed for ocean forecasting and climate prediction models
Search-and-rescue satellite-aided tracking system	Detects and locate aviators, mariners, and land-based users in distress
Space environmental sensor suite	Collects data to identify, reduce, and predict the effects of space weather on technological systems, including satellites and radio links
Total solar irradiance sensor	Monitors and captures total and spectral solar irradiance data
Visible-infrared imager radiometer suite	Collects images and radiometric data to provide information on the earth's clouds, atmosphere, ocean, and land surfaces

Source: U.S. Congress, General Accounting Office (2002).

Table 2. NPOESS funding ($ million)[a]

	FY2001 actual	*FY2002 actual*	*FY2003 estimate*	*FY2004 estimate*	*FY2005 estimate*	*F2006es timate*	*FY2007 estimate*	*Cost to complete*	*Total cost*
DoD	$71	$156	$237	$307	$259	$240	$162	$ 290	$1,925*
DoC	73	157	237	303	286	312	328	1,391	3,287†
Related DoD‡									927
Sustainment§									400

*Total cost includes approximately $204 million in funds prior to FY2001.

†Total cost includes approximately $199 million in funds prior to FY2001.

‡Related costs include launch costs.

§Sustainment funding reflects requirements after initial operating capability and may be authorized as "operations and maintenance" or "operations and research facilities."

Source: DoD Unclassified Budget Item Justification Sheet for PE 0603434F (February 2002).

[a] Information for FY2002 actual from the U.S. Office of Management and Budget; also, OMB in May 2003 indicates that the FY2004 estimate is about $30 million smaller for both DoD and DoC; the FY2005 estimate is larger by this amount for both agencies; and the FY07 estimates are $330 million for DoD and $319 million for DoC. Source: Email exchange with OMB on 22 May 2003.

Table 3. Federal budget for meteorological operations and supporting research, FY2003 ($ thousand)

Agency	*Operations*	*% of total*	*Supporting research*	*% of total*	*Total*	*% of total*
Agriculture	$13,300	0.5	$15,500	4.0	$28,800	1.0
Commerce	1,598,118	65.0	120,037	31.3	1,718,155	60.4
Defense	387,783	15.8	55,610	14.5	443,393	15.6
Interior	1,100	0.0	0	0.0	1,100	0.0
Transportation	456,386	18.6	30,862	8.0	487,248	17.1
Environmental Protection Agency	0	0.0	7,500	2.0	7,500	0.3
NASA	2,342	0.1	154,256	40.2	156,598	5.6
Nuclear Regulatory Commission	95	0.0	0	0.0	95	0.0
Total	2,459,124	100.0	383,765	100.0	2,842,889	100.0

Source: *www.ofcm.gov/fp-fy03/pdf/3-exec-sum.pdf* (accessed May 2003).

Appendix 1. Short guide to the value of information

> "We find the value of information is not zero, but it is not enormous, either."
>
> —*William D. Nordhaus, Sterling Professor of Economics, Yale University, writing about the value of weather and climate information, 1986*
>
> "If we'd been able to produce a forecast last spring that California would be deluged this winter, it would have been worth whatever research investment was involved, if only because of the human misery it would have relieved."
>
> —*D. James Baker, then administrator of the National Oceanic and Atmospheric Administration, writing shortly after heavy rains had flooded many parts of California, 1995*

So often, studies of information find that its economic benefit—its value—is smaller than conventional belief might suggest. The explanation lies in the characteristics of information and how decisionmakers use it. Decisionmakers include three communities: consumers and producers of information, public officials who fund productive investment in data acquisition and information development (including sensors and other hardware, algorithm design and software tools, and a trained labor force), and the public at large.

The value of information (VOI) is essentially an outcome of choice in uncertain situations.[12] Individuals may be willing to pay for information depending on how uncertain they are, and on what is at stake. They may be willing to pay for additional or improved information as long as the expected gain exceeds the cost of the information—inclusive of the distilling and processing of the information to render it useful.

More specifically, the general conclusions from models of information are that its value largely depends on the following:

1. how uncertain decisionmakers are;
2. what is at stake as an outcome of their decisions;
3. how much it will cost to use the information to make decisions; and
4. what is the price of the next-best substitute for the information.

[12] Hirshleifer and Riley (1979), and McCall (1982) offer overviews of general approaches to understanding the value of information.

From (1), VOI depends on the mean and spread of uncertainty surrounding the decision in question. For example, Evans et al. (1988) model the value of monitoring information for radon in homes and point out that the value depends partly on the range of remedial actions available to the household. In particular, if few actions are available, then information can have little value even if it virtually eliminates uncertainty. By contrast, if the costs of actions widely diverge, then information about radon levels may be valuable even if it reduces uncertainty very little. The authors also illustrate that VOI can be measured based on a given quality of information, or it can be measured based on how its value changes with changes in different attributes of information, such as greater frequency of collection or improved accuracy.

From (2), VOI depends on the value of output in the market—that is, the aggregate value of the resources or activities that are managed, monitored, or regulated. For example, a willingness to pay for data about oil exploration potential is in part a function of the price of gas. More formally, willingness to pay for information is *derived* demand—demand emanating from the value of the services, products, or other results that in part determine this worth. Where VOI pertains to nonmarket goods and services, output measures are also used. In the case of human health or safety, the output measure is typically expressed in terms of the value of a statistical life (a measure routinely used by government agencies engaged in safety and health regulation). Where the information pertains to the environment, the output is often expressed in terms of measures of the value of environmental quality or the value of avoided damages due to actions that may be taken in light of the information.

From (3) and (4), note that usually there are substitutes for information (for instance, traditional "windshield" surveys and aerial photography instead of satellite data for monitoring some types of land use). In addition, processing and interpreting data to make them usable can often be a major roadblock to realizing the value of data and information. A recent National Research Council study emphasizes that most state and local decisionmakers lack financial, workforce, and technical (hardware and software) resources to use remote-sensing data or apply tools for its interpretation and use (see National Research Council 2000), even for decisionmaking in which many observers say that the data could prove very useful.

Generally, the larger are (1) and (2), the larger is VOI. The larger are (3) and (4), the smaller is VOI. These values also depend on the individual decisionmaker using the information. An individual usually has subjective probabilities about the quality of the information and will use additional information to update his prior beliefs. This influence on VOI is the widely accepted applicability of Bayesian probabilities to characterize how individuals perform this updating.

Appendix 2. The value of NPOESS information

This appendix is offered by way of introduction to how to think about the value of NPOESS data. It is based on Macauley (1997).

The usual framework

The mathematical formulation that underlies the general characteristics of information is a state-preference approach. Individuals are assumed to form subjective opinions about the probabilities of two states of the world—say, the simple case of "rain" and "no rain." The value of information is in permitting the person to revise estimates of these probabilities.

Formally, the typical model follows this specification:

Maximize expected value: $E(y \mid A) = p y_{A1} + (1- p) y_{A2}$

Subject to a budget constraint: $y = P_X X + P_I I$

In the first equation, y is income, A is the state of the world (say, A1 is crop yield if it rains; A2 is yield if it doesn't rain), and p is the probability of rain. The second equation represents the limits, or budget constraint, facing the individual in spending resources to purchase, process, and use information I at price PI and to purchase and use all other goods and services X at price PX.

The result after deriving the first-order conditions from the maximization is that the person should buy additional information until the expected marginal gain from another piece of information is equal to its cost. Usually, expected value is represented by a utility function, about which different assumptions can be made as to its functional form, which in turn can proxy the individual's attitude toward risk (risk lover, risk averse, or risk neutral).

One of the best textbook examples of how this model operates is reproduced in Table A1 and Figure A1 (Quirk 1976; see also additional discussion in Macauley 1997). Suppose a farmer can harvest his entire crop today at a cost of $10,000 or half today, half tomorrow at a cost of $2,500 per day. The harvested crop is worth $50,000. Table A1 indicates the payoff to the farmer in the event of heavy rain. In expected-value terms, these payoffs are $40,000 to decision A and *p* ($22,500) + (1–*p*) ($45,000) to decision B. If *p* = 5/22.5, then the decisions give the same payoff if the farmer is risk neutral. If he were risk averse, he would want a lower value of *p* before he would wait to harvest.

Table A1. The payoff matrix (see Quirk 1976, p. 309).

Decision	*Heavy rain tomorrow*	*No heavy rain tomorrow*
A. Harvest all today	$40,000	$40,000
B. Harvest over two days	$22,500	$45,000

If it is possible to forecast the weather, then p is the probability that the forecast is for heavy rain tomorrow with certainty (and (1–p) is no rain, with certainty). Since it is a subjective probability, p can vary among different farmers. The expected payoff with information is then

p ($40,000) + (1-p) ($45,000)

If $x is the most the farmer would pay for information, then $x is equal to the difference between the expected payoff with information and the expected payoff without information. The VOI varies with p as in Figure A1.

The value is maximized at p = 5/22.5 (where $x = $3,888); as from above, this is the p at which the farmer flips a coin. Information can thus make a big difference here. The value of information is zero at p=0 and p=1, since at these extremes, the farmer is already certain in his own mind whether it is going to rain, and information is extraneous (even if the farmer is wrong).

Applications of the model can show the effects of changing the amount or quality of information as well as subsequent revisions that the individual may make of the probability (Bayesian updating).

Revisiting the discussion in the text, then, the implications for VOI from this approach are as follows:

Information is without value

- when individual's subjective beliefs are at extremes (p=0 or p=1);
- when there are no costs associated with making the wrong decision; or
- when there are no actions that can be taken in light of the information.

Information has less value

- when individual's subjective beliefs are close to extremes;
- when the costs of making the wrong decision are low; or

- when actions to take are very limited.

Information has the most value

- the more indifferent is the decisionmaker among her alternatives (she flips a coin);
- the larger are the costs of making the wrong decision; or
- the more responsive are the actions that can be taken.

Those implications explain the plight of many people in developing countries who, even if severe weather were accurately forecasted, could take few actions in light of the information, and the well-documented incentive for people to build homes along floodplains, even if these are better mapped, since the costs of making the wrong decision are mitigated by federal flood insurance.

It is important to note that information can not only influence probability but also inform the decisionmaker by affecting her expected value of the harvest based on information about crop quality and other conditions unrelated to the probability of rain. In formal terms, this means that the expressions yA1 and yA2 are both functions of I, just as the probability p is a function of I. In other words, additional information can have two effects: it permits the decisionmaker to revise her choice or to revise the probability attached to the two states or both For example, the choice whether to harvest may be influenced by information about crop health, irrespective of the probability of rain. A slightly more complex specification of the mathematical model that makes these relationships explicit is in Nicholson (1989).

Ultimately, a decisionmaker must process a host of information into a decision that reflects assessment of the probabilities of various states of the world. To the extent that information alters *a priori* probabilities (the likelihood of rain) or improves understanding of the choices themselves (the quality of the harvest) and allows individuals to make better decisions, it is a resource that has economic value.

Previous studies

Studies of the value of information have a long and far-ranging history and fall into three types of models: econometric estimation of output or productivity gains due to information, hedonic price studies, and contingent valuation surveys. The closest fit for studying NPOESS is the first of these approaches. A summary of the literature based on the productivity gain approach follows.

Most early studies of the value of information concerned the value of weather information for agricultural production and management. Johnson and Holt (1986) note 20 such studies from the 1960s on, including applications to bud damage and loss; haymaking; irrigation frequency; production of peas, grain, soybeans, and grapes (raisins); fed beef; wool; and fruit. More recently, Adams et al. (1995) observe changes in crop yields associated with phases of the El Niño–Southern Oscillation and use the market value of the yield differences to estimate the commercial value of understanding this weather phenomenon. Other studies include Lave (1963), Sonka et al. (1987), Babcock (1990), Pielke (1995), Nordhaus and Popp (1997), and Hersh and Wernstedt (2001). Some studies use a times series of the behavior of commodity prices in futures markets to infer weather-related values. Two examples are Roll (1984), who studies orange juice futures, and Bradford and Kelejian (1977), who study stock prices of wheat. Changes in futures and stock prices following weather predictions over time are taken as measures of the value of the forecast.

Additional studies have encompassed a wide variety of other topics ranging from the effects of weather forecasts on the decision to use tarps in the trucking industry (Nelson and Winter 1964), the value of information in the form of labeling on consumer products (e.g., Evans et al. 1988), the effects of information about differences in gas prices on gasoline demand in urban areas (Marvel 1976),[13] and the problem of risk assessment by insurers (one of the classic discussions of this extensive literature is in Pauly 1968). Other recent studies focus on the value of space-derived data for natural disasters (Pielke 1996; Williamson et al. 2002) and nonweather-related topics such as valuation of geomagnetic storm forecasts (Teisberg and Weiher 2000) and deforestation in the Brazilian Amazon (Pfaff 1999). The latest detailed applications of VOI are to studies of the information role played by the Internet: for example, its influence on the prices charged for goods and services in light of consumers' ability to shop on-line (Kauffman and Wood no date).

The approaches of the studies range from highly sophisticated econometric studies and detailed simulation models to less detailed, back-of-the-envelope estimates. When sources of data are abundant enough—as with the large amounts of data on crop yields, rainfall, and crop prices in the case of agriculture production—researchers can undertake rich statistical analysis.

[13] The examples of labeling of consumer products and differences in gas prices are among a large literature on "advertising as information" that uses the same conceptual framework as studies of the value of weather and other information. See, for instance, discussion in Nelson (1974).

The typical study of the value of weather information for agriculture compares expected farm profits under average but uncertain weather patterns to profits that might be expected if rain could be accurately forecast. In other topic areas, too few data may be available and the studies tend to be anecdotal.

All the studies start from the basis of the contribution of information to the value of output. It is interesting to summarize the results in the previous literature. In a review, Nordhaus (1986, p. 3) notes,

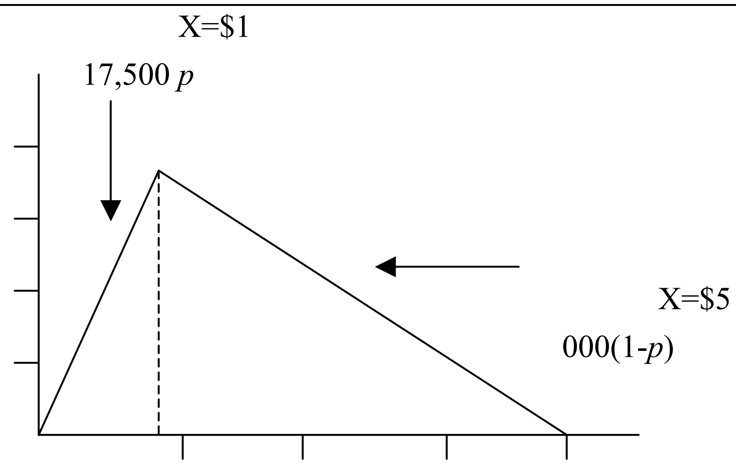
> All of the studies I know of the value of perfect information find its value to be on the order of one percent of the value of output. For example, one study found that if you halve the standard error of precipitation and temperature, say from one percent to half percent, or one degree to one-half a degree, you get an improvement in the value of the output on the order of 2 percent of the value of wheat production. A study of cotton gave the same order of magnitude. I have looked at a number of studies in the area of nuclear power and energy, trying to determine the value of knowing whether nuclear power is ever going to pan out. Again, perfect information is worth on the order of one percent of the value of the output.

Roll (1984) reaches similar conclusions in his study of the effect of weather information on the behavior of futures markets for orange juice and the effect of weather information on these markets, finding that "…there is a puzzle in the orange juice futures market. Even though weather is the most obvious and significant influence on the orange crop, weather surprises explain only a small fraction of the observed variability in futures prices."

If conclusions such as those are borne out, then compared with the value of the final product, whether measured as the value of production or capitalized into futures prices, the incremental gain from information appears small. To be sure, in industries where the value of output is in the billions of dollars, a small percentage of a large number is a large number for the value of information.

But many observers wonder why the values are not larger, as did a former administrator of the National Oceanic and Atmospheric Administration whose comment was quoted in the introduction (see Baker 1995). His conclusion might be easier after the fact ("If only I had known"). It is much more difficult to arrive at such a conclusion before the fact, however. Some of the reasons pertain to the four characteristics of information described above: using information can be costly, and there are often good substitutes for some kinds of information at lower cost. In general, it is only *ex ante* that we are willing to pay for information, because afterward it is less important. Indeed, the *ex ante* or expected value is what experts agree determines the value of information, as in the model described earlier. If the probability of an event is either very unlikely or very likely, or if the actions that can be taken to avert its effects are minimal, then this value can be quite low.

Figure A1. Value of Information (based on Quirk, 1976)



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