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

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I. Introduction

In 1994, one of the most radical restructurings in the United States' government provision of critical weather and related information services took place. After some eight previously unsuccessful attempts, a presidential directive in May 1994 led to the merger of a key part of the nation's civilian and military weather data satellite collection systems. The merger was to reduce overlap in the systems and ultimately, save money.

Most observers find that the new, jointly operated system, the National Polar-Orbiting Environmental Satellite System (NPOESS), is functioning well except for one of the problems that plagues almost every federal program - budgetary shortfalls. These shortfalls loom large for NPOESS particularly because the actual 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 to collect a host of observations to support research on global climate phenomena; international participation, on which some cost savings expectations are based, is uncertaiin; and the data processing capacity, which will be some ten times larger than current capability, requires significant expansion and upgrades. In addition, this long-lived program must also keep up with new technological developments in data collection instruments and related space technologies, but at the same time balance the possible risk associated with incorporation of innovative technology with the requirement to provide reliable, fail-safe, routinely operating weather data collection.

This paper reviews the background of the merger leading to the formation of 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 information discussion is pertinent because the merger itself focused on cost savings - but attractive as these are, 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 the rapidly expanding interest in the role the satellites could play in providing data for research 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.

Ia. 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 some 500 to 600 miles above 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 of the earth's surface about twice daily. One satellite passes over the equator at 10:00 am and the other at 1:30 pm (local time) each day. The instruments on the satellites scan an area about 1800 miles wide. The suite of instruments on the satellites detect environmental data 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 U.S. and abroad, use POES data primarily for numerical weather prediction. Some 96% of the data they use to initialize the forecasts of their models are 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 out to 1-2 days at most and any longer, 3-7 day outlooks would not be possible.

The Department of Defense began the Defense Meteorological Satellite Program (DMSP) in 1965 and has since deployed a series of over 40 satellites. Two DMSP satellites operate in orbits similar to POES but are over the equator at 5:30 am and 7:30 pm. Together with the two POES satellites, all four satellites provide weather data that are generally no more than 6 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 mid-flight 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 to monitor global auroral activity and to predict 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 for supplying global weather information. The system's nighttime passes use the visible-near infrared spectral band and this light intensification makes it possible 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.

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

Presidential Decision Directive/NSTC-2, signed by President Clinton in May 1994, directed the 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 US operational use of space for environmental purposes since the launch of the first weather satellite in 1960.

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

Ic. Funding

The NPOESS program estimates that the system will cost about $6.5 billion (in today's dollars) over the 24 year period from the 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 either be launched that year if necessary to back-up the final POES spacecraft or will be launched in 2009. The second NPOESS satellite is set for launch in 2009 to back-up the final DMSP satellite or in 2011 if it is not needed as a back up. 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 years 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 FY01 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 R&D contribution to NPOESS. Data for fiscal year 2004 show that the space agency has requested about $96 million for its NPOESS-related activity.

To provide a financial 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 supporting research (not only NPOESS) and the allocation of these funds among all agencies involved in these services. For FY03, the president proposes 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 go to the 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%.

Id. 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 Ft. 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 (in fall 2002, Northrup Grumman acquired TRW). The contract includes $2.8 billion for two satellites, with options for four additional satellites, bringing the total potential value to $4.5 billion.

As a perspective, the amount of funding for two NPOESS satellites ($2.8 billion) is about twice the size of expenditure planned for the U.S. global climate change research program in 2003 (its budget is about $1.7 billion for FY03). The contract plus the options for additional satellites (totaling $4.5 billion) is about a third of the nation's annual space budget.

II. 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 obtainable 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 their programs to joint management and as important, the agencies operated according to different protocols for distributing data. NOAA routinely shared data at no- or low-cost not only with US meteorologists but with weather agencies around the world. DoD produced weather data almost exclusively for the agency's 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 key concern of NOAA and civilian weather researchers and the preservation and enhancement of national security a key concern of DoD. For these reasons, appropriately balancing and accommodating all policy objectives loomed large as a stumbling block in the early attempts to join the two programs.

IIa. The 1994 decision

In the early 1990s, the Clinton administration sponsored a National Performance Review (NPR) of all US government operations. The NPR reported that establishing a single civilian operational environmental polar satellite program would "reduce duplication and save taxpayers a billion dollars over the next decade." 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.

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

IIb. 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 through the life of the program. 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 wholly new capacity. NOAA specifically cites these categories of potential cost reductions although the agency does not provide amounts by category:

> Development: only one system development effort is required for NPOESS rather than two efforts for designing independent systems (spacecraft, instruments, and ground command and control systems).

> Number of satellites and launches: The previously planned DMPS and POES programs were expected to require three US satellites in operation at a time, each with a design life of about four years. Eleven satellites were to be procured and launched over the 10-year lifetime of the programs. NPOESS spacecraft are to be designed for five to six years of operation. Although NPOESS will require three US satellites in operation at a time, their longer design life will require the program to procure only six satellites over a comparable 10-year life of the program.
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> Combining ground systems, operations, and management: Consolidation of the DMSP and POES operations and reducing by half the size 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.
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> 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, this list reflects the potential for at least two sources of expected savings. One source is economies of scale, in which costs are saved by sharing management and facilities. The other source is economies of scope, in which "synergies" enable 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. Since NASA would have tested them, NPOESS could adopt them with much less risk of failure or threat to NPOESS regular operations. While 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.

III. Status

As of 2003, convergence of DMPS and POES is not complete, 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 suffering intolerable cost overruns. Even though DMSP and POES are similar, the actual satellites carried some distinctively different hardware and served different mission requirements. As a result, the program is still "flying out" the pipeline of DMSP and POES spacecraft that were planned before convergence.

IIIa. R&D and "infusion" of new technology

From its Earth Science Enterprise division, NASA is carrying out its "bridging" role between the current generation of spacecraft - both NASA's 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 sometime in 2005 or 2006 to test advanced ground operations facilities and validate sensor and algorithms while the current 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.

Much of the NPOESS documentation emphasizes “substantial risk reduction” as a goal of the program. 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 balancing of infusing new technology to insure that NPOESS is adequately "state of the art" while not jeopardizing the program's requirement to provide a reliable supply of weather data is at the heart of maintaining a long-lived technology program.

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IIIb. Climate research and NPOESS

An additional role for NPOESS - that of collecting data to support science 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 if new instruments were appropriately calibrated and data were archived, the data could support the examination of long-term trends in climate processes as well (see National Research Council, 2000). The NPOESS data could supply a large array of measurements of atmosphere, oceans, land, and the space environment. The NAS also urges that the NPP become more than a “one-time” opportunity to bridge the technology gap between POES/DMSP and NPOESS. The NAS studies recommend that NPP should become a permanent centerpiece for maintaining state-of-the-art data collection to facilitate the role of NPOESS data in climate research.

IIIc. Data management

Because the data flow from NPOESS spacecraft will be quite large, the Congress and the General Accounting Office (Congress’s investigative arm) have asked NOAA to develop and implement new plans to deal with managing all of the data. Whereas current polar 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 of the data that are expected to be collected. 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, the IPO has satellite control authority only 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 primary DMSP and two primary POES spacecraft until NPOESS spacecraft are available around 2008. While the primary command and control facilities and data distribution center for both systems has been centralized in Suitland, Maryland, organizational structures are still evolving, with program management of POES and DMSP split between two offices (management is to move eventually to one office under NPOESS).

IIId. Cost savings to date

Tracking the actual cost savings under NPOESS to date and the potential size of future savings is difficult for several reasons. One reason is that historic cost data are incomplete and inconsistently reported (they have different formats, cost categories, and timing of expenditures). The size of future savings is unclear because the scale and scope of the program changes based on R&D, the vagaries of international cooperation, and the changing 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 these 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 to 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 operations costs during the first two years of the program, and reducing the size of staff has 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 nor yet reflected in the NPOESS budget data or projected cost savings. In addition, Europe changed its plans and decided not to build and fly a spacecraft with the appropriate capability specifically to support NPOESS. Instead, NOAA and Eumetsat are discussing compatibility in the technical operation and data collection systems of Europe'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 Europe's decisions, thus keeping final plans for instrumentation of NPOESS in flux. Some additional international participation is underway, 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.

IV. 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.

IVa. Management design

In their study of the formation of NPOESS, Johnson and coauthors (2001) list these reasons for the establishment of joint programs such as NPOESS:

Improving interoperability among components and reducing duplication
Reducing development and production costs
Meeting similar interagency service requirements
Reducing logistics requirements through standardization

To achieve these goals, approaches to interagency cooperation range from formally establishing a joint or integrated program office (IPO) as for NPOESS, to creating a wholly new, functional 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 and coauthors find that NPOESS as designed seems positioned to meet these goals for several reasons. A Memorandum of Agreement (MOA) signed by all three agencies in 1995 provided for each agency to have representation in the IPO; for personnel to be collocated in a central office; and for integration to take place over several years and thus for time to be allocated to solving problems. The MOA designated NOAA as the "lead" agency; operations and the international interface went to this agency. DoD, with its significant acquisition experience, was the lead in this area. The assignment of acquisition responsibility to DoD eased DoD's concerns about whether future systems would meet DoD requirements.

IVb. 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 - although by necessity. They have been inadequate for enforcing an effective bargaining relationship after reorganization.

IVb1.The "contract" and funding. The MOA was in essence an incomplete contract as the formal mechanism to govern the joint venture. Important ingredients of a contract - say, among companies, individuals, and institutions in the private sector - from real estate to corporate mergers - is "who pays" and "how much." But such contracts are even more effective when they 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 progam would operate, assets would be merged, and responsibilities would 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 to 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 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 this attention to details about who pays, the MOA can not force any actual commitment of agency resources. The MOA cannot mandate the size of budgets nor can it 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 implementation of 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 brought significant budget cuts.

IVb2. The budget process. Perhaps one of the biggest stumbling blocks in NPOESS funding is the problem of differences in the budget planning cycles among partners. An integrated program requires more effort to maintain funding levels for several reasons.

Asymmetry in importance. One reason is that 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 battlegroup - a really large project for NOAA, representing some 15 to 20% of the agency's some $3 billion budget and highly visible. Within DoD, however, NPOESS is a small part of even the DoD space budget and it not a top priority among most Pentagon leaders. Within DoD, NPOESS competes with a wider range of programs and is an easy target for cuts to pay for military equipment. As a result, in FY03 DoD reduced planned NPOESS spending by some $50 million (later restored by Congress) and for FY04, there is also discussion that would cut DoD's share. Because the cost share is 50%-50%, these cuts would imply a smaller NOAA budget for NPOESS and result in an overall smaller NPOESS budget.

Difficulties in coordination and negotiation. Another difficulty in program funding for an integrated program is that 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 different bureaucracies each operating on different budget cycles (so information is due to comptrollers at different times of the fiscal year). The DoD budget cycle begins a few months before DoC's.

Support for the converged program must also be garnered among key members from a larger number of congressional committees that influence the program, including leaders in the House and Senate

Authorization and Appropriations committees, both on the Defense and 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, keeping budget examiners at the Office of Management and Budget (OMB) and at the Office of Science and Technology Policy briefed with the best possible information also takes time and resources to maintain executive support. The IPO considers OMB to be a common grounds for coordination and resolving disputes, but even within OMB, NPOESS must coordinate with three separate auditors for DoD, DoC, and NASA. The NPOESS IPO estimates that keeping the full complement of funding decisionmakers informed consumes about 80% of their work hour.

R&D and technology infusion. Another challenge with implications for funding the integrated program arises from attempts to take advantage of new technology, but not at the risk of harming the operational reliability of the system. The nature and rate of incorporation of R&D can be a source of disagreement, and a tendency in government programs that seek to balance system operations and research is for too conservative adoption of new technology. Failure -- of entire systems or even a single instrument -- can be expensive in terms of loss of data, replacement costs, and political and investigative inquiry that attends high cost or highly visible programs. A related and longstanding 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 towards 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 sector industry may spend in their bids to win the award to build follow-on instruments and spacecraft. The issue here is not only the actual costs of preparing the bid; rather, another concern is the extent to which companies expend lobbying and other efforts to influence the selection process. With consolidation of the two systems into one, do companies tend to work even harder if just one system is competed than if multiple systems are competed. These influence costs - when resources are expended say, through lobbying efforts-are also a cost borne by society as a whole (the shareholders of the companies). Another view is the federal government's "desire to keep its defense contractors healthy," a view expressed by industry financial analysts after the NPOESS contract award to TRW (which competed against Lockheed). 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. An additionally large issue related to funding is the definition and measurement of customer requirements - which data and how much to collect and disseminate, decisions that in turn determine instrumentation and influence operations for NPOESS. The problem of mediating requirements is longstanding 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 (JPL) in the 1970s (see Raiffa, 1982). JPL faced a large dispute among aerospace scientists as to the selection of trajectories for the two Voyager probes to Jupiter and Saturn (the probes were originally named Mariner). The selection of the trajectories was important because they would significantly affect the nature of the science investigations. To resolve the dispute, JPL divided the approximately eighty scientists who wanted to use data from the probes into ten 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 of the suggested responses and to 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 pair 17 with a value of .73, then this could be interpreted to mean that that team evaluated getting pair 17 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 also 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 helped to understand and communicate among the teams and with management. But they also viewed the process with some skepticism because they suspected that some of the teams strategically "gamed" their vote rather than voted "honestly."

The value of NPOESS data. This 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 is a key characteristic of the nonmarket nature of the goods and services provided by government (good discussion is in Mueller, 1989). Agencies do not typically supply a number of units of output as such, but levels of activities. For instance, the 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 thought 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. Measurable "units" of inputs - 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 measurement 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).

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

There is a large literature on 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, nor 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 this gap in understanding the potential value of NPOESS information looms so large as a possible stumbling block for effective program funding, box 1 illustrates some of the simple 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 references therein).

Taken together, these challenges for NPOESS confront a program that has a strong management basis upon which to build -- the IPO structure seems sound. The problem of funding is part of 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.

V. Conclusions

The success of NPOESS is in the proof of 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. Issues of data management - both infrastructure and international sharing; the infusion of new technology of an appropriate nature and at an appropriate rate;and adequate funding are among the necessary ingredients. But saving money is only part of the funding equation. The other part is improving understanding of just how much the NPOESS data are worth - a value question common to almost all government supplied services. Future research about the value of NPOESS data could go far in supporting the program by improving understanding of this “benefit” side of the cost calculus.

Table 1: Planned NPOESS Instruments

Instrument Name	**Description**
Advanced technology microwave sounder	Measure microwave energy released and scattered by the atmosphere and use with infrared sounding data from NPOESS' cross-track infrared sounder to producer daily global atmospheric temperature, humidity, and pressure profiles
Aerosol polarimetry sensor	Retrieve 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	Collect microwave images and data to measure rain rate, ocean surface wind speed and direction, amount of water in the clouds, and soil moisture, and temperature and humidity at different atmospheric levels
Cross-track infrared sounder	Measure Earth's radiation to determine the vertical distribution of temperature, moisture, and pressure in the atmosphere
Data collection system	Collect environmental data from platforms around the world and deliver them to users worldwide
Earth radiation budget sensor	Measure solar short-wave 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	Measure 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	Collect data to measure the amount and distribution of ozone in the Earth's atmosphere
Radar altimeter	Measure variances in sea surface height/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	Detect and locate aviators, mariners, and land-based users in distress
Space environmental sensor suite	Collect data to identify, reduce, and predict the effects of space weather on technological systems, including satellites and radio links
Total solar irradiance sensor	Monitor and capture total and spectral solar irradiance data
Visible/infrared imager radiometer suite	Collect 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 ($ in millions)[a/]

	FY2001 actual	FY2002 actual	FY2003 estimate	FY2004 estimate	FY2005 estimate	F2006 estimate	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 FY01.
**Total cost includes approximately $199 million in funds prior to FY01.
***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 US Office of Management and Budget; also, OMB in May 2003 indicates that the FY04 estimate is about $30 million smaller for both DoD and DoC;the FY05 estimate is larger by this amount for both agencies; and the FY07 estimates are $330 million for DoD and $319 million for DoC. Email exchange with OMB on 22 May 2003.

Table 3. Federal Budget for Meteorological Operations and Supporting Research FY 2003 (in thousands of dollars)

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
EPA	0	0.0	7,500	2.0	7,500	0.3
NASA	2,342	0.1	154,256	40.2	156,598	5.6
NRC	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

Box 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.**

The mystery of the "value" of information…. So often, studies of information find its economic benefit -- its value -- to be smaller than conventional belief might suggest. The explanation lies in the characteristics of information and how decision makers use it. Decision makers include three communities: consumers and producers of information, public officials whose job is to 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 VOI is essentially an outcome of choice in uncertain situations.[1] 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 information, 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:

(1) how uncertain decision makers 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.

From (1), VOI depends on the mean and spread of uncertainty surrounding the decision in question. For example, Evans, Hawkins, and Graham (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 quite 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 – for instance, greater frequency of collection or improved accuracy.

From (2), the value 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. In other words, 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 value of the services, products, or other results that in part determine this worth. In cases where the VOI pertains to nonmarket goods and

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

services, output measures are also used. For instance, 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). In cases 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), it is important to note that usually there are substitutes for information (traditional "windshield" surveys and aerial photography are used instead of satellite data for monitoring some types of land use, for instance). In addition, processing and interpreting data to make them usable can often be a major roadblock to realizing the value of data and information – for example, a recent National Research Council study emphasizes that most state and local decision makers 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, 2001), even for decision making 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 the value. These values are also dependent on the individual decision maker who is using the information. An individual usually has subjective probabilities about the quality of the information and will make use of additional information by using it 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: The Value of 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 these 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, A_1 is crop yield if it rains; A_2 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 P_I and to purchase and use all other goods and services X at price P_X.

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 towards risk (he can be a risk lover, or be risk averse, or be risk neutral).

One of the best textbook examples of how this model operates is reproduced in table 1 and figure 1 (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 1 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.

would want a lower value of *p* before he would wait to harvest.

Table 1. The payoff matrix (see Quirk, 1976, p. 309)

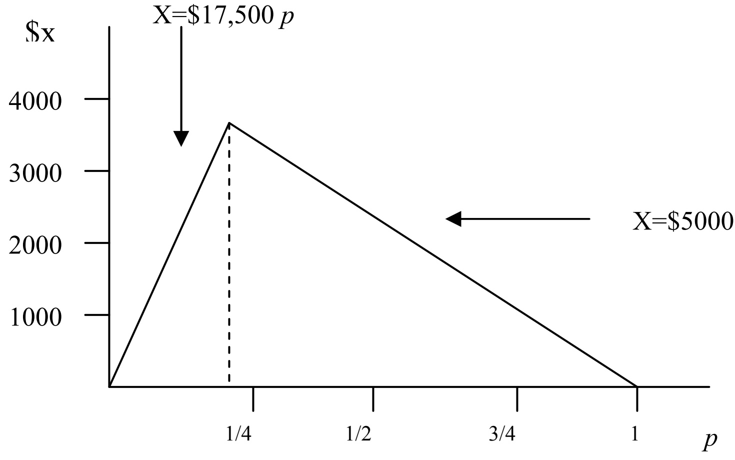
Nature: **Decision:**	**Heavy rain tomorrow**	**No heavy rain tomorrow**
A. Harvest all today	\$40,000	\$40,000
B. Harvest over two days	\$22,500	\$45,000

If it is possible to forecast the weather, then p is the probability that the information the farmer receives is that there will be a 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 1.

Figure 1. Value of Information (based on Quirk, 1976)



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 the biggest 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 the VOI from this approach are:

A. 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
When there are no actions that can be taken in light of the information

B. Information has less value
When individual's subjective beliefs are close to extremes
When the costs of making the wrong decision are low
When actions to take are very limited

C. Information has the most value
The more indifferent is the decision maker among his alternatives (flips a coin)
The larger are the costs of making the wrong decision
The more responsive are the actions that can be taken

From these, the plight of many populations in developing countries even if severe-weather forecasts were more accurate is apparent (in many cases, there are few actions that can be taken in light of the information) and the well-documented incentive for people to build homes along floodplains, even if these are better mapped, is also reflected (the costs of making the wrong decision can be low, mitigated by federal flood insurance).

It is important to note that information can not only influence probability, but it can also inform the decision maker by affecting his 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 y_{A1} and y_{A2} 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 decision maker to revise his 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.

From this discussion, ultimately a decision maker 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. The studies 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 much of the literature based on the productivity gain approach follows.

Most of the early studies of the value of information were on the topic of the value of weather information for agriculture production and management. Johnson and Holt (1986) note twenty such studies dating from the 1960s on, including applications to bud damage and loss; haymaking; irrigation frequency; production of peas, grain, soybeans, grapes (raisins); fed beef; wool; and fruit. More recently, Adams and co-authors (1995) observe changes in crop yields associated with phases of the El Nino-Southern Oscillation (ENSO) and use the market value of the yield differences to estimate the commercial value of the ENSO phenomenon. Other studies include Lave, 1963; Sonka and coauthors, 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 (1978) 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 (for example, see Evans, Hawkins, and Graham, 1988); the effects of information about differences in gas prices on gasoline demand in urban areas (Marvel, 1976)[2]; 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 and Williamson and coauthors, 2002) and non-weather-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, the importance of information available on the Internet in influencing prices charged for goods and services in light of consumers' ability to shop on line (Kauffman and Wood, 2000).

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 – for example, the large amounts of data on crop yields, rainfall, and crop prices in the case of agriculture production – researchers can undertake rich statistical analysis. 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 of 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 of these studies, Nordhaus (1986, p. 3) notes that

> 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 thought 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 these are borne out, then compared to the value of the final product, whether measured as the value of production or capitalized into futures prices, the incremental gain from

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[2] 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.

information appears to be small. To be sure, in industries where the value of output is in the billions of dollars, a small percent of a large number is a large number for the value of information.

But many observers wonder why the values are not larger. This observation is illustrated in an editorial by a former administrator of the National Oceanic and Atmospheric Administration and 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 why pertain to the four characteristics of information described above – using information can be costly, and there are often good substitutes for different kinds of information at lower cost. In general, it is only *ex ante* – before the event – that we are willing to pay for information, because afterwards 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.

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