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Space Technologies and Climate Change
Implications for Water Management, Marine Resources
and Maritime Transport

Chapter 6

Tool Box for Policy Makers: Costs, Benefits and Investment Decisions

Investment in space systems must be sustained in order to meet the challenges of climate change, natural resources management and activities that affect the environment, such as maritime transport. However, it cannot be taken for granted that the funding will be forthcoming, not least because cost-benefit evaluations of future investments are far from straightforward. This chapter suggests how improvements might be made to the policy makers' tool box for assessing and deciding on space-related investments. The first section discusses some key notions useful for defining space programmes (e.g. R&D, infrastructure, notion of costs); a second reviews methodologies used to evaluate benefits of space programmes in more detail, using specific case studies as illustrations; a third section develops an innovative infrastructure approach; and a final section provides prospective views on the use of risk management approaches for decision making in the field of space investments.

Table 6.1. **Main evaluation methods for analysing large programmes**

Selected methods	Description
1. R&D Programmes' Impact Analysis	
Scientific returns	Quantifiable measure of publications
Economic returns	Quantifiable parameters to try and link R&D intensity and economic activity (*e.g.* technology transfers)
2. "Classic" return on investment techniques:	
Key performance indicators	Quantifiable performance measures
Cost-benefit analysis (CBA)	Measures tangible and intangible benefits and assesses these against costs
Break-even analysis	The amount of time necessary for benefits to equal costs
Transaction costs	Segmentation methods to calculate use and benefits to different user groups
Cost-effectiveness	Marginal costs for achieving specific goals
Net present value	The difference between the present value of cash inflows and outflows at a given discount rate
Initial rate of return	The discount rate that makes net present value of all cash flows equal to zero
Value assessment	A method that captures and measures factors unaccounted for in traditional return on investment (ROI) calculations
Portfolio analysis	A method that quantifies aggregate risks relative to expected returns for a portfolio of initiatives
Real options analysis	Analysis of capital investments in terms of the options they contain, with uncertainty accounted for by risk-adjusting probabilities ("equivalent martingale approach")
3. Infrastructure approach	Benchmarking investments in space systems against terrestrial infrastructure investments
4. Risk management approach	Addresses investments in satellite systems from the point of view of monitoring and mitigating major risks and reducing uncertainties

Source: Adapted from OECD, 2006b.

Definitions and key notions for evaluating space programmes

In most OECD member countries, governments increasingly require that public agencies assess the benefits and costs of their operations while exploring the possible monetisation of these benefits. For the past 20 years the space-related agencies and industry, particularly in Europe, North America and India, have examined ways of estimating benefits from space programmes (Sankar, 2007). There is a general sense that over time, the cost of launching and operating a satellite is offset by the many benefits it provides; nonetheless, measuring those benefits is a challenge. In the case of specific applications that use space assets in large or small measure, such as water management or maritime zone control, there is added complexity intervening in the final decisions (*e.g.* about the value of satellite data, gauges on the ground, specific actions led by actors on the ground such as civil protection in case of floods). This section reviews some definitions and key notions for evaluating space programmes.

Definitions

Space programmes provide an interesting paradox: they are often considered and funded as research and development (R&D) programmes, but act in many cases as key infrastructures delivering unique public and private services. This subsection reviews a number of terms.

Space programmes – The first full-scale space programmes date from the late 1940s – early 1950s. From the start, they consisted of R&D projects to develop technologies and know-how to send objects into space and utilise this new dimension for science and security purposes. Today, institutional space programmes worldwide still cover a wide range of technologies (*i.e.* launchers, satellites, space stations, ground segment) and disciplines (*e.g* telecommunications, earth observation, navigation, astronomy), sometimes with "accompanying" programmes to involve new users (*e.g.* commercialisation of technologies outside the space sector). Space programmes are usually undertaken nationally via dedicated agencies, but also often within a bilateral or multilateral international co-operation framework, particularly in the European context. Since the 1980s, a number of private actors have conducted their own space programmes directly, for profit (*e.g.* telecommunications satellite operators, commercial launch providers), but always within a regulatory framework put in place by governments (OECD, 2005).

Space applications – "Applications" are the resulting outcomes of many space programmes. Sometimes they are actively sought, to develop specific space products and services (*e.g.* satellite television); on occasion such results are accidental. The data derived and/or signal issued from a large number of programmes initiated for purely scientific purposes can be deemed relevant by large communities of users. Today the value chains for space applications vary, depending on the commercial or scientific benefits of the data or signal provided. That is where the destination between pure R&D programmes (set up for a limited period) and applications (often to be set up on an enduring operational basis) becomes blurry at times. Even in the case of military space programmes, it has been historically difficult to shift programmes from the science and technology environment to the operational environment (GAO, 2008a).

Space infrastructure – The term "space infrastructure" encompasses all systems, whether public or private, that can be used to deliver space-based services. These include both the space and underlying necessary ground segments. As identified in OECD (2005), there are two complementary and interlinked space-based infrastructures. The first one focuses on the "front office", *i.e.* the one "user-oriented" and designed to provide information-related services including communications, navigation signals and earth observation data to governments and society at large. The second concerns the essential enabling "back office", *i.e.* the space transport, satellite manufacturing and servicing infrastructure. This notion of space infrastructure will be explored further in the chapter.

Assessing the costs

In order to assess the net benefits of a programme, it is essential to have an idea of the costs of developing it. Producing a comprehensive cost analysis of any space system can be daunting. Historically, major space projects have tended to be markedly complex and lengthy and therefore costly, even in the case of commercial satellites. Space systems remain high-level technological products, the results of long-term and constant research and development. Even when a satellite platform is "standardised", furnishing a prototype that can be reused for other missions, the addition of new instruments or sensors adds development costs and complexity. Recent advances in small satellites have alleviated some costs, but even then the overall budget for a programme may not be easily envisaged (OECD, 2004). This is especially true for expected operations costs, which may be much larger than previously anticipated. Such is the case with an unexpectedly increased satellite lifetime (*e.g.* the European ERS-2 satellite, designed for three years in orbit but still operational today after more than 12).

Three main categories of costs are usually estimated in any R&D project:

- The direct costs of a new system or integration initiative (*e.g.* financial costs), which are usually the easiest to identify and analyse.
- The opportunity costs, which are the losses or costs to the organisation that result from developing a new system rather than using the resources on alternative projects (the engineer who spends several hours learning a new computer system to prepare for a new project instead of working on another short term project, for example, has incurred a limited opportunity cost).
- The indirect costs, such as those for infrastructure maintenance, depreciation or the overall administration expenses, are usually based on uncertain assumptions and limited knowledge of actual impact of shared resources.

Three main techniques are used to estimate these costs in most high-technology sectors, including in the space sector during a project's life cycle (*i.e.*, research and development, production, operations and support costs). These methodologies, along with their advantages and disadvantages, are summarised in Table 6.2. Parametric modelling, used for brand new systems, is particularly challenging, as there are no traceable historical data (Glad, 2005).

Table 6.2. **Cost estimation techniques for space projects**

Method	Characteristics	Advantages	Disadvantages
Cost by analogy	Derived from costs taken from a technically similar programme	Costs traceable to historical data	Not sensitive to programmatic details
Parametric modelling	Derived from relationship of costs to physical data (*e.g.* weight, power consumption)	Provides a rough order of magnitude estimate (*i.e.* specific cost drivers) if the system characteristics are already defined	Not traceable to historical data, and some cost drivers can be underestimated because of innovative combinations of subsystems
Engineering modelling	Detailed information and cost element estimates prepared at the lower practical level of task design and definition (*e.g.* work breakdown structure, or WBS)	Can use the work breakdown structure elements' historical cost data	Requires a very detailed design description from the start; time consuming and not possible for very innovative projects

Source: Adapted from Cohendet, 1999.

Space systems often differ greatly, and despite the hundreds of satellites sent into orbit since the 1950s they have so far generally been produced in rather small quantities each time. Many environmental satellites can even be qualified as prototypes. The technological risks also represent an inherent difficulty, which may cause costly delays (Box 6.1). Cost estimates for space systems and their derived applications are thus a domain in which it is difficult to generalise.

Tracing benefits to satellites

As seen in Chapter 4, satellites have some unique capabilities. But it can be difficult to trace the benefits back to space-based systems that provide specific links, signals or data. It is even more complex to then try and pinpoint the benefits of a specific instrument or sensor on one satellite.

As an example, the satellite MetOp 1 is Europe's first polar-orbiting satellite dedicated to operational meteorology. MetOp carries onboard 11 instruments, composed of a set of "heritage" instruments provided by the United States and a new generation of European instruments that offer improved remote sensing capabilities for many different disciplines.The new instruments already increase the accuracy of temperature humidity measurements, readings of wind speed and direction, and atmospheric ozone profiles.[1] However, improved weather forecasting products and environmental monitoring systems could be affected as much by improvements in data thanks to MetOp as by better modelling techniques, which are in full development.

By the same token, a wide range of geophysical parameters can be derived from a single satellite instrument. The Special Sensor Microwave Imager (SSM/I) was mentioned several times in Chapter 4. This sensor is carried onboard several American meteorological satellites (*i.e.* F13, F14 and F15), allowing 24-

Box 6.1. **Challenges in evaluating space programme costs**

The case of the US Department of Defense's space acquisition programme

The US Department of Defense (DOD) invests heavily in space assets to provide the armed forces with intelligence, navigation and other information critical to conducting military operations. In fiscal year 2008 alone, the DOD expects to spend over USD 22 billion on space systems. The majority of major acquisition programmes in the DOD'S space portfolio have, however, experienced problems during the past two decades that have driven up costs and schedules and increased technical risks. At times, cost growth has come close to or exceeded 100%, causing the DOD to nearly double its investment without realising a better return. Along with the increases, many programmes are experiencing significant schedule delays, as much as seven years. A number of reasons for these problems have been identified by the Government Accountability Office (GAO). They include optimistic cost and schedule estimating; the tendency to start programmes with too many unknowns about technology; inadequate contracting strategies; contract and programme management weaknesses; the loss of technical expertise; capability gaps in the industrial base; tensions between laboratories that develop technologies for the future and acquisition programmes; the different needs of users of space systems; and diffuse leadership. The DOD is taking a number of actions to address the problems reported by the GAO.

Source: US Government Accountability Office (GAO), 2008b.

hour coverage. Its data are used to study a myriad of elements: ocean surface wind speed, an area covered by ice, the age of ice, ice edge, precipitation over land, cloud liquid water, integrated water vapour, precipitation over water, soil moisture, land surface temperature, snow cover and sea surface temperature. If one includes its predecessor (the Scanning Multichannel Microwave Radiometer SMMR carried on board several meteorological satellites), SSM/I data have in fact been available from late-1978 to the present. This is a case where is one instrument has been providing valuable data – for decades – to a variety of scientific and operational users. Other sensors with the same versatility, and which can be used to observe other parameters than those for which they were originally designed, include for instance the GOME-2 spectrometer. Developed to monitor ozone, the sensor can also be used for water vapour detection. As another example, soil moisture, ice and snow can be monitored by ASCAT-MetOp, whose original purpose was wind measurements.

One method used to discriminate among various sensors' contributions on satellites was attempted in the ROSE GSE study (Whitelaw *et al.*, 2004). The idea was to determine which data were the most likely used by an application, and estimate the number of pictures that may needed by a specific user to conduct his activity. The methodology used was to take the marginal cost of the proposed/future missions, then estimate a proportional cost of the missions based on the levels of use of a specific instrument in proportion to overall mission data use. This determined an appropriate fraction of the total mission cost. As mentioned by the authors (Whitelaw *et al.*, 2004), the method is valuable as it is a move towards addressing the real cost of satellite-based information. The estimate nevertheless remains very approximate given the difficulties of estimating mission costs (including satellite construction, launch and operations); levels of use in proportion to overall total usage; shared use of given acquisitions; and actual mission lifetimes. The results of this type of study could usefully be transferred to other application studies using benefit transfer methods and clear caveats. The lingering problem is that the overall study ignores by definition the overall costs of the earth observation systems, as the prices of satellite imagery – even if still high in many cases – do not reflect the total costs of setting up and operating the infrastructure.

Table 6.3. **Cost base for the ROSE study (2004)**

Mission/instrument	Mission Cost (million euros)	Duration years	Annual cost	Instr. % of mission	Annual instrument cost	Duty cycle	Ops factor	Images per year	Cost per scene (euros)
ENVISAT ASAR	2 300	5	460	50	230.00	10	75.0	157	680
ENVISAT MERIS	2 300	5	460	20	92.00	100	25.0	525	600
ENVISAT ATSR	2 300	5	460	5	23.00	100	50.0	1 576 800	15
ERS 1/2	500	5	100	50	50.00	10	75.0	157 680	317
NASA MODIS (Terra and Aqua sats)	1 130	5	226	20	45.20	100	25.0	525 600	86
NOAA AVHRR	202	5	40	60	24.24	100	90.0	1 892 160	13
Radarsat-1 FB,IM,WS	426	5	85	100	85.20	10	75.0	157 680	540
SPOT HRS, HRG	671	5	134	80	107.36	100	15.0	315 360	340
Orbview 2 SeaWiFS	43.5	8	5	100	5.44	100	25.0	525 600	10
Radarsat-2	380.25	5	76	100	76.05	10	75.0	157 680	482

Source: Whitelaw, *et al.*, 2004.

Timeliness of studies

Technological advances can affect both costs and benefits. Cost-benefit studies may often become quickly out of date, as technology evolves and the cost efficiency and capability of systems improve over time. For example, there have been rapid advances in satellite communications and earth observation technologies in recent years. This means that more can be done (*i.e.* higher benefits) for less (*i.e.* lower costs) with the latest generation of earth observation satellites, and future generations could be even more effective. Another aspect deals with the maturity of services at least linked partially to space-based data. As seen in Chapter 4, most of the sensors that were identified for climate and water management missions are for research purposes. As such, they aim to demonstrate capabilities and may have a rather short time scale. Prospective views are therefore often needed, and render the cost-benefit exercises even more difficult.

Diminution of recognised benefits due to external factors

Concerning the use of new technologies, the general purposes for which data or signals are used can directly affect the expected benefits from a system. This can of course relate directly to the role of space systems and climate change. If some aspects of climate management receive undue attention or inaccurate appreciation, that might in turn diminish recognition of the anticipated benefits derived from space systems. Conversely, justification for new technologies and claims as to their efficacy may lack critical scrutiny. That either situation is possible indicates a need for the appraisal process to involve a full, close, and systematic examination of claims concerning the benefits of a technology or product. And that includes identifying and assessing the conditions under which the claimed benefits might or might not materialise.

Measuring the impacts of R&D programmes

The current assessment efforts of public science and research programmes in general still fail to capture the full range of impacts derived from R&D. As identified by OECD (2007e), the methodologies used are still evolving. Moreover, the choice of a specific analytical technique for impact assessment is not random but context-specific. The timing and objective of the assessment, as well as the nature and scope of the public R&D funded, are factors that must be borne in mind when selecting an analytical technique from an existing toolbox. Assessment of space programmes is also affected by those challenges, as will be shown in this section. A first subsection looks at scientific return measurement issues, and a second reviews macro and micro approaches used when assessing economic returns.

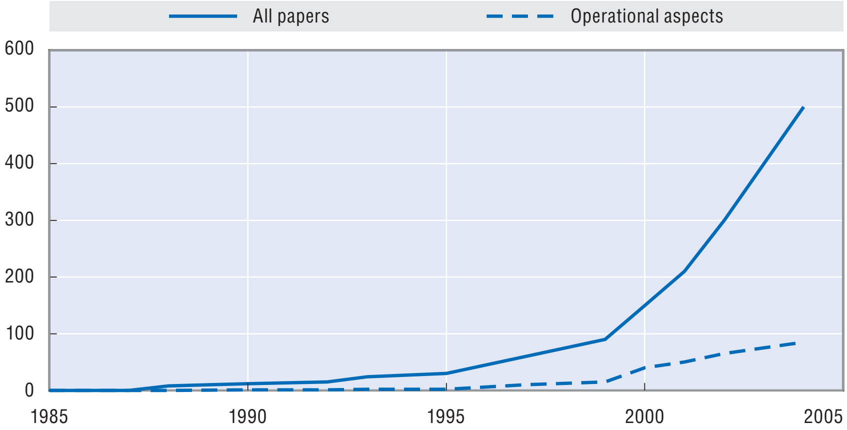
Scientific returns from R&D programmes

Science has historically been a major objective of space programmes. In terms of scientific returns, one useful quantitative measure concerns the number of refereed publications based on space missions. However, the true impact of a mission could go significantly beyond the publications that specifically mention it, as new research and operations techniques are often developed in the framework of a given mission.

In the case of the Tropical Rainfall Measuring Mission (TRMM) for example – the mission mentioned earlier between NASA and the Japan Aerospace Exploration Agency (JAXA) – the launch triggered a flood of research that greatly broadened understanding of tropical weather systems and their forecasting, as well as improved quantification of the hydrological cycle and the climate system (NRC, 2006).

The studies captured in Figure 6.1 span a broad spectrum of topics. They include contributions to increasing the basic scientific knowledge needed for future applications (*e.g.* descriptive and diagnostic studies) as well as operational applications (*e.g.* monitoring weather features, notably tropical cyclone activity; climate monitoring; numerical weather prediction and climate model development; and model assimilation of TRMM data in forecast operations). Papers addressing operational aspects (lower curve) lag behind scientific papers (higher curve), but that will change as operational use of the TRMM data substantially increases (*i.e.* as quality control issues are resolved and data are progressively integrated in applications).

Figure 6.1. **Scientific returns measurement of refereed publications directly related to TRMM**



Note: Data for the figure were obtained by the referenced authors through searching the *Institute for Scientific Information's Science Citation Index* for papers that mention TRMM either in the title, abstract or keywords. Papers dealing with operational aspects are based on terms such as "real-time,""operational" and "assimilation."

Source: Matthias Steiner, Princeton University, cited in NRC, 2006.

It is challenging to anticipate scientific benefits for most first-generation satellite sensors due to a lack of prior experience with similar data (NASA, 2002). But often the planning and forecasting of a satellite mission lifetime hinge on those potential scientific returns. Taking into account this uncertainty, space agencies' resource planning for most earth observation missions has focused on a relatively short-term, high-payoff approach based on expected fundamental scientific and engineering returns. This has caused considerable dissatisfaction in the climate science community, where long-term observations are essential to fundamental research.

As an example, the success of the Tropical Rainfall Measuring Mission and its continuing "good health" led to several extensions of the mission.

Conclusions about the benefits of extending TRMM to and beyond the "fuel point" (the maximum time when the satellite's re-entry in the atmosphere can still be safely controlled) are compiled in Table 6.4. Although the additional cost of extending TRMM from December 2004 to November 2005 was estimated at approximately USD 4 million,[2] the many derived intangible benefits of pursuing operations seemed prior to the extensionto outweigh the costs (NRC, 2006). Since 1998, TRMM has in particular provided near-real-time information for operational purposes (behaviour of tropical cyclones, rainfall), and no other satellite can replace it for the moment. The TRMM mission was extended again in 2005; it is expected to last until at least 2010 (as of June 2008), when the first of a series of planned follow-on Global Precipitation Measurement Mission satellites is due to be launched.

Table 6.4. **Anticipated operational and research contributions due to extending the TRMM satellite missions to the fuel point (approximately December 2005) and beyond**

Anticipated contributions of TRMM up to the fuel point (when controlled TRMM re-entry is still possible)	Additional anticipated contributions of TRMM beyond the fuel point (*i.e.* in addition to what is gained up to the fuel point)
OPERATIONS ● Another year of TRMM Microwave Imager (TMI) and precipitation radar (PR) data enhancing near-real-time rainfall products** ● Another year of lightning data for air traffic advisories* ● Realising PR's potential as a global rainfall reference standard* ● Another year of PR and TMI data for weather and climate prediction models**	**OPERATIONS** ● Technology demonstration of the endurance of the first precipitation radar forecasting** in space ● Improved forecasts from the operational numerical weather prediction**
RESEARCH ● Overlap with CloudSat radar operations and the A-Train satellite experiment ** ● Overlap with the Coriolis WindSat sensor mission* ● Unique opportunities to enhance field experiments (TCSP, TEXMEX-II)** ● Unique opportunities to enhance international research programmes (GEWEX, THORPEX, Hurricane Field Program)** ● TRMM's precipitation radar provides calibration reference for the current global precipitation measurement mission-like Oscillation cycle* constellation of microwave satellite sensors** ● TRMM is a catalyst for tropical cyclone research (*e.g.* research on convective bursts, tropical cyclone eye wall replacement cycles, improved forecasting of inland flooding during hurricanes)** ● Longer TRMM record needed for tropical cyclone forecasting* ● Longer TRMM record needed for climate research* ● Foster improvement in moist physics parameterisation for climate models, numerical weather prediction, and related assimilation systems by evaluating models of clouds and precipitation physics*	**RESEARCH** ● Unique opportunities to enhance field series** ● Developing the next generation hurricane forecast model** ● Better characterisation of interannual variability and the El Niño-Southern Oscillation cycle* ● Seamless transition into global precipitation measurement (GPM) operations* ● Realisation of a GPM-like prototype * Avoiding researchers being ill-prepared for future global precipitation measurement operations**

Note: A single asterisk differentiates applications that use TRMM data as the only or primary component of a research or operational activity from those that use TRMM data as a complementary component (marked with a double asterisk). There is a grey area between these two categories, but the distinction serves as a first-order attempt to differentiate between essentially stand-alone contributions and complementary but still unique contributions of TRMM.

Source: NRC, 2006.

Economic returns of R&D programmes

In addition to evaluating scientific returns, different methods derived from economic theory using macro and micro analysis techniques have been used over the years to assess the economic effects of space technologies. These are detailed below with references to specific studies.

i) The macroeconomic approach

Economic growth theory has long postulated that improvements in technology are the source of long-run development (Solow, 1956; Romer, 1990) and that differences in technology are the main determinant of differences in income per capita across countries. The macroeconomic approach is often used in the case of large R&D programmes or infrastructure to provide cost-benefit information, via economic input-output analyses. The main objective is to measure the growth of productivity in a region or country generated by the investment.

Input-output analysis specifically shows how industries are linked together through supplying inputs for the output of an economy. Factors that can be used to construct indicators of productivity are for example employment, expenditures, income, production of goods and services and competitiveness. Such factors are of interest at both the national and regional levels. Results of these analyses are derived from macroeconomic data such as changes in GDP, which can then be compared to changes in capital. The challenge when interpreting the material is to find the causal linkages between the programme/infrastructure investments and the rise in productivity. However, the findings of these studies are sometimes contentious, and highly dependent on the choice and evaluation of appropriate variables over long periods, as well as the calculations used to assess their cause and effect mechanisms.

As an example, the Federal Aviation Administration's Office of Commercial Space Transportation (FAA/AST) published a report in 2006 on the impacts of commercial space transportation and related industries in other economic sectors, specifically in terms of revenues and jobs that are generated (FAA, 2006). The economic impact analysis used an input/output method and the Regional Input-Output Modelling System (RIMS II) developed by the Department of Commerce, Bureau of Economic Analysis. The space sector, as defined in the study by the FAA, was found to be responsible – via direct, indirect and induced impacts – for USD 98 billion in economic activity in 2004 and 551 350 derived jobs throughout the United States. All major US industry sectors were affected positively to some extent (*e.g.* the information services sector, manufacturing, finance and insurance, healthcare and social assistance). As a comparison, using the same methodology the economic impact of the civil aviation industry was found to be over 10 times that of commercial space transportation and enabled industries. Methodology-wise, input-output analyses are valuable methods to measure economic impacts. On the other hand, one inevitable drawback of this type of analysis stems from the lack of precise space statistics, since the statistical codes used for the study by definition cover more than just space activities (OECD, 2007f).

Other studies have been conducted using input-output techniques to study the macroeconomic impacts of space programmes at local or regional levels. Whenever many employees from a single organisation are working in one area, it is assumed that economic spillovers can be felt in a given region (the same concept applies to the economic effects of large military bases). As an example, with more than 1 600 NASA scientists and engineers, the John C. Stennis Space Center strongly influences the surrounding communities. In 2005, the NASA centre's direct global economic impact was estimated at a total of USD 691 million, with a USD 503 million impact on Mississippi and Louisiana communities within a 50-mile radius. Impact studies have also been conducted for French Guiana, host of "Centre Spatial Guyanais", the European spaceport. Onsite space activities represent 20% of the French department's GDP in 2005, with 1 350 persons employed in the sector and 5 800 derived jobs in other sectors (one direct job being responsible for 4.4 induced jobs). In addition, actors involved in the space sector are responsible for 40% of local taxes and 60% of French Guiana imports (CNES and INSEE, 2005).

The microeconomic approach

Microeconomic analysis studies the behaviour of individual organisations, firms and customers and their interactions, usually determined by market demand and supply. The use of supply and demand curves is however not always directly applicable to space systems and their derived applications because of immature products (new technologies) and non-quantifiable demand. A real technical limitation of microeconomic analysis is the daunting task of assessing accurately all the markets liable to be affected by a specific space technology, and not just when it is innovative (Eurospace, 1994). Different microeconomic approaches are presented below.

Numerous studies of "spin-offs" have been conducted in the United States since the 1960s (such as outputs from NASA's Apollo programme), notably of the transfers from space-related hardware and know-how to other sectors (*e.g.* medical imagery). The value of spin-offs is however not easily quantifiable, and at times oversold concepts have been detrimental (*e.g.* Teflon as space technology).

In Europe, the BETA (*Bureau d'Économie Théorique et Appliquée*) of the University Louis Pasteur of Strasbourg has developed over the past 20 years a methodology extensively applied by them to assess the indirect economic effects of ESA contracts in European member countries (BETA, 1989, 1997; Bach, 2002).

The method focuses on the indirect effects generated by an R&D project such as a space programme or a space contract with a commercial firm. Those effects generally occur in four areas: technology (*e.g.* sales of the same product to other customers, or improvement in the current product line based on the space technology developed); marketing (*e.g.* reputation and image enhancement resulting from the execution of the contract for ESA); organisation and method (*e.g.* better performance thanks to standards and management techniques used during the ESA contract); and critical mass (*e.g.* preserving or increasing the number of employees in the space sector). The effects are identified and measured through extensive interviews with personnel in each firm that received a contract over the period studied. Using the same methodology over different periods, BETA measured the effects of ESA contracts in Canada and European countries, with generally positive findings for the space sector. But as mentioned in Amesse and Cohendet (2001), "most of the effects are concentrated within the space sector and are increasing over time as specialisation of the industry increases. There is also a tendency for effects to be concentrated within contracting firms, leaving less and less room for subcontractors." Investment in the space sector has traditionally remained in the space sector. Even for product development, it is shown that technological effects "are mainly short term (improved products and resale of space products to other foreign customers); while the development of new products is a less important factor and decreases over time." This trend could be expected due to the very specific nature of space-related manufacturing, but the increasing number of downstream applications in numerous disciplines and uptake of space-based data could signal change.

A combination of macro and micro approaches could provide better estimates, although it will still fail to address potentially larger non economic impacts (Sankar, 2007). The Belgium federal government commissioned a study to researchers at the Université Libre de Bruxelles (ULB) to evaluate the social and economic contribution of the federal scientific research institutes linked to the space programme (Capron and Baudewyns, 2007). Despite a relatively small space budget compared with the major space powers, Belgium ranked eighth in 2005 in terms of national public space budgets as a percentage of GDP (OECD, 2007f). The Belgian space sector employs some 1 600 scientists, engineers and technicians (Beka, 2007). In order to calculate those contributions, the ULB is planning to use both input-output tables and a large survey to identify and quantify the economic impacts derived from three institutes.

Judging from the examples presented so far, large-scale R&D programmes in the space sector have been the focus of many socio-economic studies over the years. However, all such studies face inherent limitations, very similar to those in other types of public R&D impacts analysis (Box 6.2). When assessing the results of these studies there is often a reluctance to link socio-economic outcome measures too directly to research programmes, as there are many

Box 6.2. **Challenges encountered when analysing the impacts of public R&D**

- ***Causality.*** There is typically no direct link between a research investment and an impact. Research inputs generate particular outputs that will then have an impact on society. As it is indirect, this relationship is difficult to identify and measure. It is also almost impossible to isolate the influence of one specific factor (research output) on one impact, because the latter is in general affected by several factors that are difficult to control for.
- ***Sector specificities.*** Creation and channelling of output to the end-user will differ depending on the research field and industry. This renders ineffective the use of one single framework for assessment.
- ***Multiple benefits.*** A basic research impact may have several dimensions, not all of which are easily identified.
- ***Identification of users.*** Identification of all end-users who benefit from the research outputs can be difficult and/or costly, especially in the case of basic research.
- ***Complex transfer mechanisms.*** It is difficult to identify and describe all the potential mechanisms for transferring research results to society. Some studies have identified mechanisms of transfer between businesses or between universities and businesses. These models are mainly empirical and often reveal little of the full impact on society of such transfers.
- ***Lack of appropriate indicators.*** Since appropriate benefit categories, relevant transfer mechanisms and end-users are often lacking, it is also difficult to define and measure appropriate impact indicators related to specific research outputs.
- ***International spillovers.*** The existence of knowledge spillovers has been well documented and demonstrated. As a result, specific impacts could be partially the result of internationally performed research instead of national research investments.
- ***Time lags.*** Different research investments vary in the time it takes them to have an impact on society. Any measurement may thus prove premature, especially in the case of basic research.
- ***Interdisciplinary output.*** Research outputs, *e.g.* improved skills, may have different impacts, and it may be difficult to identify them all in order to evaluate the contribution of the specific output, let alone that of the research investment.
- ***Valuation.*** In many cases it is difficult to come up with a monetary value of the impacts so as to make them comparable. Even if identifiable, noneconomic impacts may be difficult to value. There have been some attempts to translate some of these impacts (such as the economic savings associated with a healthy population or the calculation of opinion values) into economic terms, but these have typically remained partial and open to subjectivity.

Source: OECD, 2007e.

intervening steps that may distort the causal link. The next sections present other return on investment approaches (direct and indirect market valuation techniques), notably using cost-benefit analysis.

"Classic" return on investment techniques (direct and indirect market valuation)

The most common economic measurement of any technology's value is the calculation of return on investment (ROI), a ratio of costs to benefits. To calculate the ROI of a space system, it is necessary to total the costs of deploying the system (*e.g.* hardware, software, maintenance, training and so forth) – and divide the total by the potential benefits (such as improved productivity, decreased cost of operations, increased revenue and better customer satisfaction rates in the case of commercial systems). However, as mentioned in previous sections, space systems are by nature very specific, due to their complexity, risks and lengthy research and development. There is extensive academic literature on cost-benefit analysis (CBA), also sometimes called "project appraisal" or "policy evaluation", for many current societal interests. Methodologies for benefit assessment continue to evolve.

The challenge of placing monetary value on technologies and the services they deliver is not just a space problem. Whether cost-justifying new purchases, assessing the value of existing assets or making a business case for future architectural directions, valuing a technical system is a complex and often subjective exercise. Monetary or financial valuation methods fall into three basic types, each with its own repertoire of associated measurement issues (Table 6.5); not all of them can be used to estimate satisfactorily the benefits derived from space systems. They are:

- Direct market valuation.
- Indirect market valuation.
- Survey-based valuation (contingent and group valuation).

Direct market valuation techniques

Direct market valuation techniques are the obvious methods for assessing established commercial space applications, since the economic importance of a service can be directly measured in monetary units. But value can also be extrapolated by the service contribution to employment and productivity, *e.g.* in terms of the number of people whose jobs are related to the use or conservation of the service.

Market price – This classic method uses exchange value, based on the marginal productivity cost that products and services have in trade. It is mainly applicable to well-identified commercial space-based products and services (*e.g.* phone conversation using a satellite link).

Table 6.5. **Monetary valuation methods, constraints and examples**

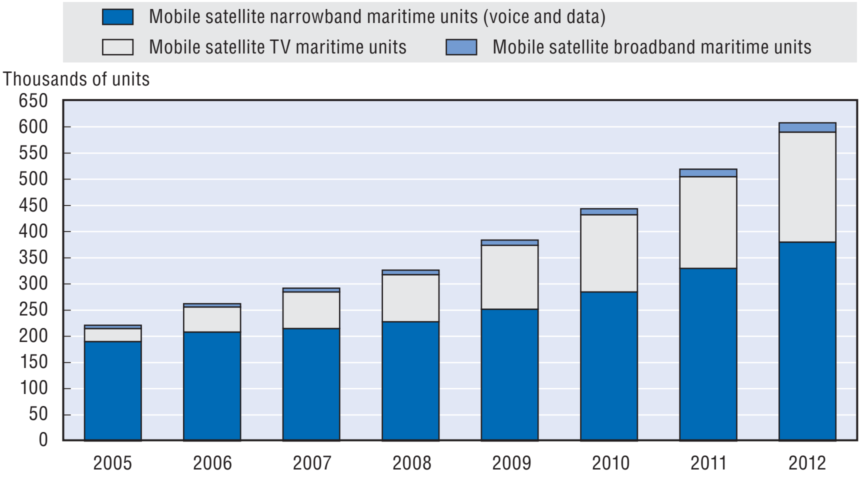
	Method	Description	Constraints	Examples
1. Direct market valuation	Market price	Measures the exchange value (based on marginal productivity cost) that products and services have in trade	Market imperfections and policy failures distort market prices	Mainly applicable to identified commercial products and services (*e.g.* phone conversation using a satellite link), "goods", and some cultural (*e.g.* recreation) and regulating services
	Factor income or production factor method	Measures the effect of services on loss (or gains) in earnings and/or productivity	Care needs to be taken not to double-count values	Number of people whose jobs are related to the use of specific space service (*e.g.* telecommuting via satellite communications); for ecosystem analysis: natural water quality improvements that increase commercial fisheries catch
	Public pricing	Measures public investments, *e.g.* land purchase, or monetary incentives (taxes/subsidies) for ecosystem service use or conservation	Property rights are sometimes difficult to establish; care must be taken to avoid perverse incentives	Investments in watershed protection to provide drinking water, or conservation measures using satellite monitoring systems
2. Indirect market valuation	Avoided (damage) cost method	Services that allow society to avoid costs that would have been incurred in the absence of those services	It is assumed that the costs of avoided damage or substitutes match the original benefit. However, this match may not be accurate, which can lead to underestimates as well as overestimates	The value of a satellite-based flood control service can be derived from the estimated damage if flooding were to occur.
	Replacement cost and substitution cost	Some satellite services could be replaced with other systems		The value of a satellite system can be estimated from the costs of obtaining information from another source (substitute costs)
	Mitigation or restoration cost	Cost of moderating effects of lost functions (or of their restoration)		Cost of preventive expenditures in absence of communication services (*e.g.* lives potentially lost)
	Travel cost method	Use of ecosystem, water-related services may require travel and the associated costs can be seen as a reflection of the implied value	Overestimates are easily made. The technique is data-intensive	Part of the recreational value of a site is reflected in the amount of time and money that people spend while travelling to the site
	Hedonic pricing method	Reflection of service demand in the prices people pay for associated marketed goods	The method only captures people's willingness to pay for perceived benefits. Very data-intensive	Presence of communication in remote areas (via sat.) increases the attractiveness of area
3. Surveys	Contingent valuation method (CVM)	This method asks people how much they would be willing to pay (or accept as compensation) for specific services through questionnaires or interviews	There are various sources of bias in the interview techniques. Also there is controversy over whether people would actually pay the amounts they state in the interviews	It is often the only way to estimate non-use values. For example, a survey questionnaire might ask respondents to express their willingness to increase the level of water quality – which may rely on satellite data – in a stream, lake or river so that they might enjoy activities like swimming, boating or fishing
	Group valuation	Same as contingent valuation (CVM) but as an interactive group process	The bias in a group CVM is supposed to be less than in an individual CVM	See CVM above

Source: Adapted from De Groot, 2006 and OECD, 2006b.

In the satellite communications sector, the maritime markets are already well identified. They are quite diverse and include different types of users with different needs in terms of satellite services: the merchant ships (with fleet and ship management services, crew calling); the fishing community (messaging, position reporting services); the oil and gas offshore industry (large data transfers and positioning via satellites); government (data transfers *at* sea, encrypted services), passenger/cruise ship management (social calling, broadcast services); yachts/pleasure crafts (social calling, messaging, position reporting); and finally other services, including the international safety services, including equipment onboard required by the international Maritime Organisation (*e.g.* GMDSS, EPRIB) (see Chapter 4).

The maritime markets are dynamic ones, although with an adoption rate that is relatively slow compared to the land-mobile segment. According to NSR data (2007), the number of satellite units on maritime platforms will grow overall from 225 000 in 2005 to over 605 000 in 2012 and provide revenues of over USD 1 billion at the end of 2012 (Figure 6.2). Traditionally, the maritime markets mostly consist of narrowband products with voice and data terminals adapted to the rugged high-seas environment. With a little over 193 000 units in-service in 2005, the narrowband maritime market could grow to 381 000 units representing USD 470 million of revenues at the end of 2012. Direct broadcast satellite TV in the shipping and cruise industry has been on a high growth curve for the last few years and is a key product for crew comfort and passenger entertainment, growing from around 25 000 units in 2005 to possibly 200 000 in 2012 and with retail revenues in the latter year of over USD 221 million

Figure 6.2. **Global Satellite Maritime Units In Service, 2005-2012**



Source: Adapted from NSR, 2007.

(NSR, 2007). Broadband capabilities allowing Internet access are also becoming recognised as an important part of ship operations and the market is growing steadily. Consequently, a large number of firms are developing new products and services to target commercial merchant fleets (Thuraya, 2008).

Production factor – In economic theory, production factors are the resources employed to create goods and services. The factors can cover a large range of elements, such as labour, capital and land, but also technology. The use of space technology is seen in some economic sectors as a key factor in rising productivity or efficiency. A number of examples follow, based on particular experiences in fisheries, maritime transport, maritime zone control and weather forecasting.

Adoption of satellite navigation-related technologies in fishing fleets began in the mid-1980s, and general technology rollout and adoption began in the 1990s all over the world. The fisheries sector has mainly benefited in terms of reduced operating costs attributable to the use of GPS-enabled plotting systems. According to a recent Australian study (ACIL Tasman, 2008), some fishers stated that they saw their productivity rise by 50% or more as a result of GPS technology. Indeed, total Australian fishing industry output has increased by around 50% since the late 1980s (from around 180 000 tonnes in 1988/89 to around 270 000 tonnes in 2003-04). Other improvements in technology (boats, sonar scanning, nets, etc.) will also have contributed to this trend. The best available scientific evidence indicates that the fishing power of the fleet increased by around 12% due to the uptake of GPS and plotters. The cumulative addition to fishing output over time that can be conservatively attributed to the use of GPS plotters was estimated at 4.14% of output in 2007, equivalent to around AUD 88 million at 2007 prices (ACIL Tasman, 2008).

With regard to maritime transport, as seen in previous chapters, sea ice covers around 10% of the world's oceans – and a key satellite application comes from monitoring of sea routes. In the Arctic, the Northwest Passage (United States and Canada) and the Northern Sea Route (Norway and the Russian Federation) are two important seasonal waterways. Satellites allow monitoring of the sparse network of air, ocean, river and land routes that circumscribes the Arctic Ocean. The value of monitoring sea routes has been studied over the years and the benefits from satellite observations – although not always easily quantifiable due to numerous variables – are deemed important. In 2005 the Canadian Ice Services (CIS) was the only Canadian government operational user of RADARSAT-1 data. RADARSAT-1 provides observations over a wider geographical area in much less time than with an aircraft. As a result, CIS has been able to improve its operational efficiency. It has been estimated that over five years (1995 to 2000), the net average annual savings to CIS operations have been about CAN 7.7 million per year (CAN 38.5 million over five years), with the same per year benefits continuing up to and including the eighth year of operations for RADARSAT-1. The Canadian Coast

Guard (CCG), the largest direct customer of CIS products, has perhaps benefited most. The CCG Ice Operation Centres can provide improved routing information to commercial shipping, which allows for faster transit times. The shipping industry has also benefited from the accuracy of RADARSAT information to produce ice charts. The shipping companies believe that as a result of these ice charts, savings in their transit time through ice-infested waters are an estimated CAN 18 million a year. Other benefits included less damage to ships and reduced need for CCG escorts. The CCG has estimated dollar savings in both operating costs and transit time for those escorts to be between CAN 3.6 million and CAN 7 million a year, depending on the severity of ice conditions (CSA, 2005).

Box 6.3. **Detection of oil pollution in the Mediterranean Sea**

In the framework of its Monitoring Illicit Discharges from Vessel (MIDIV) programme, the Joint Research Centre (JRC) of the European Commission was tasked by the Italian Ministry of Environment to detect oil pollution in the Mediterranean Sea over the period 1999-2004 near the Italian coasts. Italy was then considering the creation of an environmental protection zone along some of its coasts. Using 18 947 radar images from archives (hence no aerial or ship validation) of the European satellites Envisat, ERS-1 and ERS-2, 9 299 possible oil spills were detected. It was estimated that a rather low spatial resolution (cheaper than higher resolution imagery) of about 200 metres was sufficient for statistical investigations of marine oil pollution. Most of the spills were away from the coasts, indicating deliberate intention to avoid possible legal actions in territorial waters. An interesting finding from the research links the decreasing number of oil spills in some areas to recent decisions by France to create an environmental protection zone, with increased aerial surveillance (JRC, 2007).

In 2006, an operational satellite-based oil slick detection service integrating SAR data from Envisat and the Canadian Radarsat satellite was set up for all European waters under the European Maritime Safety Agency (EMSA). The service, named *CleanSeaNet* has a long-term objective to be integrated into national and regional response chains, so as to strengthen operational pollution response for accidental and deliberate discharges from ships and assist coastal states in locating and identifying polluters in areas under their jurisdiction (EMSA, 2008). The service provides notification of a pollution event within 20 to 30 minutes of the satellite overpass. By integrating the SAR oil slick information with vessel information, it becomes possible to identify potentially responsible vessels. In parallel, a number of complementary or sometimes competing national and regional demonstration projects are under way.

Source: JRC, 2007; EMSA, 2008.

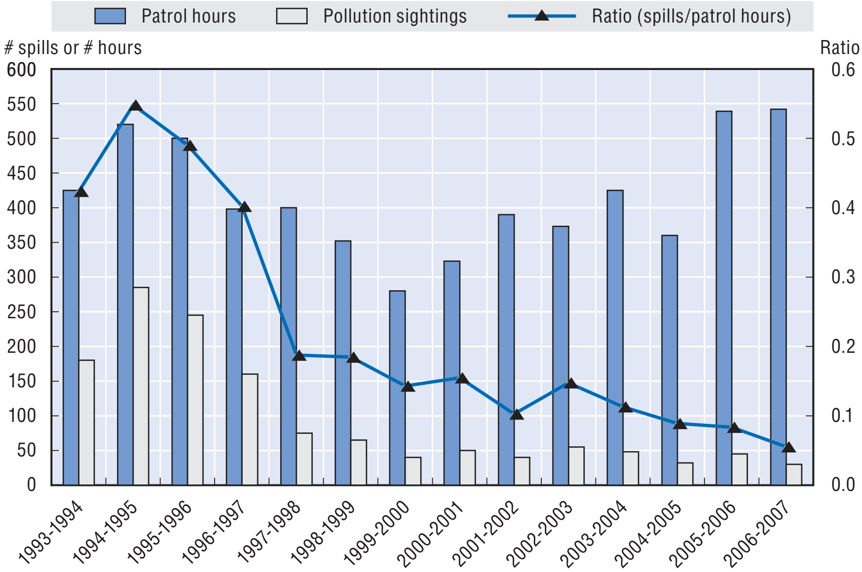
To offer another illustration of efficiency derived from satellites, there are a number of studies concerning maritime zone monitoring, for illegal fishing and ship-sourced pollution. A direct link between the usage of satellite imagery and the decrease in polluters or illegal fishers in a given area is not clear. However, the improved ship detection over large geographic zones enabled by integrating satellite imagery with other tools (*e.g.* aerial patrols) is indeed beginning to help deter illegal fishing and oil spills.

In the case of illegal fishing, in 2004 France set up a ground receiving station on the Kerguelen Island (South Indian Ocean), to monitor its exclusive economic zone. All Envisat and Radarsat-1 satellite overpasses there are acquired, processed and correlated with the French fishing Vessel Monitoring System (authorised fishing ships in the area are required to carry onboard a detector) – and followed up by ship patrol – to protect the local stocks from illegal fishing (Greidanus, 2005). Since then, it has been estimated that the surveillance system has cut the number of illegal fishing incursions in the vicinity by nine-tenths by late 2005, and no illegal incursion was detected in 2007 (French Assembly, 2008).

With regard to ship-sourced pollution, Canada has a challenging task when trying to monitor its enormous maritime area. The Canadian Exclusive Economic Zone (EEZ) extends 200 nautical miles offshore and contains over 5.5 million square kilometres, often bordering a complex crenulated coastline. However, according to data collected since 1993, the National Aerial Surveillance Programme has had important impacts on reducing pollution from passing ships in the Pacific Canadian EEZ (Serra-Sogas *et al.,* 2008). It is thought that the NASP is particularly effective as a deterrent because it involves regular flights over ships based at least in part on the indications provided by Radarsat satellite imagery to detect potential polluters (Figure 6.3).[3] The increasing effectiveness of radar imagery contributed to Norway's decision in 2003 to invest in the Canadian Radarsat programme. The objective was primarily to secure access to operational radar data for national oil spill detection, ship detection and ice monitoring services that had been developed by using data from ESA research satellites. In addition to the Canadian Exclusive Economic Zone example, the trend of decreasing oil spills was also found in parts of the Mediterranean Sea; there too it is linked to recent decisions by France to create an environmental protection zone with increased aerial surveillance and use of satellite imagery (EC /JRC, 2007).

Finally, an interesting example comes from the United Kingdom in terms of efficiency derived from satellite data for meteorological forecasts. The Meteorological Office and several Numerical Weather Prediction centres (NWP) have undertaken impact studies concerning data from polar-orbiting satellites. This is a complex question since the weather prediction products can be affected as much by improvements in modelling techniques as by improvements in initial

Figure 6.3. **Reduction in oil spills in the Canadian Pacific Exclusive Economic Zone (1993-2007)**



Source: Sogas *et al.*, 2008.

data. Nevertheless, the success of a forecast system can be measured in terms of accuracy through an index devised for the purpose (BNSC, 1998). A Met Office internal review of the situation early in 1998 showed that some 3.5% improvement in the index could be attributed to use of the raw satellite data stream operated by NOAA (at that time, Europe only operated satellites in geostationary orbit and relied on US low earth orbit polar satellites for data over sections of the Atlantic). Further improvements introduced during 1999 raised the index by about 5%, and impact studies showed that about 2% of that 5% could be attributed to better processing of NOAA data. The imagery was therefore still considered an essential forecasting aid. On the technical side, it was estimated that this development and provision of instruments had allowed the Met Office to develop a skill base, enabling it to act as an intelligent customer for procuring "best value for money" satellites through the various space programmes. Cost savings and improved performance through these activities was estimated to be many times the cost of retaining the team.

Indirect market valuation

When direct market valuation techniques are not sufficient (in terms of markets, efficiency, productivity), it is necessary to resort to more indirect means of assessing values. A variety of valuation techniques can be used to establish the (revealed) willingness to pay (WTP) or willingness to accept compensation (WTA) for the availability or loss of these services (De Groot, 2006). In particular for the space sector, these include new services that allow society to avoid costs that would have been incurred in the absence of those services. A prime example relates to flood management.

Flood control was the subject of very early cost-benefit studies of water resources (Brouwer, 2005); today, fairly sophisticated CBA procedures are used on a routine basis in most OECD countries. The focus is very much on probabilistic analysis of floods, the costs of their control and the damages avoided through that control. Damages are fairly easy to estimate; they range from property damages, impacts on wetlands and health risks to welfare losses arising from the "fear of floods". Many case studies have been conducted over the years as new space systems have come online; these assess the latter's role in flood management (*e.g.* high resolution satellites, increasing use of combined existing space systems), and the development of easier-to-use GIS systems and broadband telecommunications. Satellite monitoring generally provides large area coverage; it is relatively inexpensive once the satellite is in orbit if one can get the imagery at low cost (*e.g.* case by case agreements). However, it still requires calibration with ground-measured data. And although there are broad uses for remote sensing in delineating land use/land cover, its application in locating a very distinct water line with high accuracy is limited. Much of the problem is that vegetation shifts on the ground are not clearly evident in imagery (Smith *et al.*, 2004). Despite those limitations, the main benefits identified over the years include avoided costs of damages and improvement of operational efficiency (Table 6.6). In Italy the improvement of forecasting and early warning tools (including the use of space-based data) allowed a marked reduction in human losses from 1994 to 2000, according to the Italian Civil

Table 6.6. **General flood management benefits**

Better forecasting with damage costs avoided	Weather forecasting combined with hydrological models permits more advanced flood and flash flood warnings. Hence, – Reduced casualties and injuries (as well as consequences for public health). – Reduced economic damages (to property and economic activities) as well as environmental damages (especially relating to forest fires).
Improved operational efficiency	The response during the flood can be well targeted, satellite data providing the basis for extent mapping and real-time monitoring, assessing damage to infrastructure, meteorological assessments, evaluation of secondary disasters, resulting in other costs savings: – Reduced prevention costs (prevention plan elaboration, flood protection investments, forest maintenance). Quantification and assessment of the potential impacts were based on information and validation provided by the end-users directly involved in the projects. – Reduced anticipation costs (flood forecasting services, fire alert systems). – Reduced crisis management costs (rescue activities, firefighting, recovery).
Reconstruction	Satellite use speeds the reconstruction efforts and loss assessments (insurance).

Source: OECD, 2005 and Risk EOS, 2005.

Protection Agency (Soddu, 2006). The International Charter for Space and Major Disasters signed in October 2000 is another interesting case. It is a mechanism maintained by nine space agencies that agreed to supply their respective optical and radar imagery in times of natural disasters to requesting countries and international organisations. The Charter was activated 175 times in the last eight years. The latest activation was made in May 2008, following the earthquake in Sichuan province: China, a Charter member, used data as inputs to elaborate maps for rescuers.

Table 6.7. **Actions and estimated benefits of using space assets for flood management**

Location	Action	Benefits
Arles, France (2003)	Water pumping	During Arles flooding in the South of France (2003), 25 million m^3 of water were pumped by French civil protection. It took three weeks to get the city dry again. By comparison, in 2001 – before the International Charter for disaster was active and regular satellite observation was possible – it took three months for the cities and villages in the French *département* of the Somme to be dry again, because of the difficulty controlling the efficiency of water pumps on a large scale.
North Carolina, United States (2003)	Maps for flood insurance	North Carolina did an update of its flood insurance maps using remote sensing data. A cost-benefit analysis by the US Geological Survey mentioned that the state would gain USD 3.35 for each dollar spent on the programme, and lose USD 57 million each year that it did not have updated maps (NRC, 2003). As an added benefit, the maps could be used for community planning and other purposes.
California, United States (1997-98)	Evacuations based on weather forecast	Improved forecasts of the 1997-98 El Niño events are estimated to have saved California residents on the order of USD 1 billion compared to the costs of a similar event in 1982-83, which was not forecast.

Source: OECD / IFP.

The survey approach (contingent and group valuation)

One way to estimate a potential service's value is to ask users directly what they would do in a hypothetical scenario, via contingent valuation techniques. For example, a survey questionnaire might ask respondents to express their degree of willingness to pay for a service or an activity. Although methodological advances have been made with this approach, it is not without its problems (Box 6.4). Over the past few years, the related method of "contingent choice" – asking respondents whether or not they would pay a predetermined amount – has also gained popularity, since it eliminates some of the weaknesses of contingent valuation. Another approach involves group deliberation, or "group valuation". Here, small groups of people are brought together in a moderated forum to deliberate about the economic value of specific services.

Box 6.4. **Background on the contingent valuation method**

The contingent valuation method is perhaps the most widely used stated preference method or survey-based technique. Particularly from the 1990s onwards, the method has been applied extensively to the valuation of environmental impacts in both developed and developing countries. The range of environmental issues addressed is wide: water quality, outdoor recreation, species preservation, forest protection, air quality, visibility, waste management, sanitation improvements, biodiversity, health impacts, natural resource damage and environmental risk reductions, to list but a few.

Although still controversial, this direct survey approach to estimating individual or household demand for non-market goods has been gaining increased acceptance among both academics and policy makers as a versatile and comprehensive methodology for benefit estimation. This acceptance was in large part based on the conclusions of the special panel appointed by the US National Oceanic and Atmospheric Administration (NOAA) in 1993 (Arrow *et al.*, 1993) following the Exxon Valdez oil spill in Alaska in 1989. The panel concluded that, subject to a number of recommendations, contingent valuation studies could produce estimates reliable enough to be used in a (US) judicial process of natural resource damage assessment. It is now over a decade since the NOAA deliberations, and recent important developments have included the publication of official guidelines for using stated preference research to inform UK public policy and state-of-the-art guidance on most aspects of non-market (environmental) valuation for the United States. Those developments have not been restricted to application of these guidelines and guidance in the field of environmental economics. There has also been important cross-fertilisation with health economics and, more recently, cultural economics. Most promisingly, much more is now known about the particular circumstances in which stated preference methods will work well – in terms of resulting in valid and reliable findings – and where problems can be expected. Such findings have had an important bearing on evolving best practice in the design of contingent valuation questionnaires.

Source: OECD, 2006.

In the space sector, those survey approaches are now used regularly to test the interest of potential users of future space systems and services. One defining factor for all of them is that the expected benefits usually concern the setting up of entire information systems, in which satellite data or signals are crucial but only one component in the long value chain. Follow the results of studies concerning: potential transit-time savings enabled by upcoming meteorological systems; cost avoidances in flood management; oil pollution monitoring benefits derived from satellite navigation and earth observation data; and potential benefits derived from better snow information.

In his report entitled *Benefits of NPOESS for Commercial Ship Routing: Transit-Time Savings*, Kite-Powell (2000) estimated the average time saved for container ships from routing with and without the future US National Polar orbiting Operational Environmental Satellite System (NPOESS) data (the system was then programmed for a 2007 launch). For Atlantic transits, the average time saved without NPOESS data is estimated to be 4 hours per transit; with NPOESS data it is estimated to be 7 hours per transit (a gain of 3 hours). For Pacific transits, the average savings without NPOESS data is 12 hours and with NPOESS data 21 hours (a gain of 9 hours). These savings of 3 and 9 hours are attributed to NPOESS working in concert with more traditional observations from the Polar-orbiting Operational Environmental Satellite (POES), the Defense Meteorological Satellite Program (DMSP), ground-based Doppler radar systems, airborne sounders and radar aircraft. Those time savings translate into an expected average annual benefit to ship routing from NPOESS data (in the two decades following the launch) of about USD 95 million per year. Because of the US share of world trade, perhaps 20% of the total benefit – some USD 20 million per year – could be realised by consumers in the United States.

Concerning flood management, a number of studies have focused on the future capabilities of upcoming systems and expected cost avoidances. The Risk-EOS study (2005) provides the results for a fully European risk information system, operating from 2012. Taking into account methodological constraints, the estimation mentioned of flood damages avoided has to be seen as very conservative. This is due to the fact that the economic costs avoided of flash flood damages are underestimated: it is not always easy to differentiate between flash floods and plain floods in available statistics.

Table 6.8. **Maximum benefits that can be expected from the European Risk-EOS services for floods**

Flood risk	Maximum expected benefits from Risk EOS (in 2020)	Benefits in 2012		Benefits in 2020	
		Value (million euros)	%	Value (million euros)	%
Flood preparedness and prevention	● 0.1% flood protection and operating and maintenance	1.1	0.6	7.4	0.8
Flood damages	● 2% of flood economic damages	70.8	36.2	351.6	38.5
Flash floods casualties	● 20% on flash flood casualties ● 2% on plain flood casualties ● 2% flood consequences on public health	27.25	13.9	118.7	13
Flood crisis management	● 2% flood rescue activities ● 2% flood recovery costs	1.5	0.8	7.3	0.8

Source: Risk EOS, 2005.

With regard to oil pollution monitoring from space, in the GSE *Real-time Ocean Services for Environment and Security* (ROSES) study, a number of scenarios/ options have been identified to give an indication of the potential and prospective economic benefits a full detection system for oil spill could provide in Europe (Whitelaw *et al.*, 2004). In Option 1, only basic services are provided; global routine and on-request local services are offered, but with no advanced modelling capabilities. An Option 2 provides a full product set including all the types of service, while Option 3 extends the oil spill monitoring services to address marine primary productivity and sea level and climate change monitoring applications as well. The results are summarised in Table 6.9.

Table 6.9. **Potential societal benefits from an oil spill detection system (ROSES study)**

	% impact totals	Resulting benefit	Rationale
Option 1	Equivalent of 1.5% cleanup bill x 3 for discharge volumes	EUR 6.48M	Improved cleanup operations, % impact on the cleanup budgets averaged annually. Provision for two major events also included.
	Equivalent of 1.5% cleanup bill x 3 for discharge volumes	EUR 8.26M	Better detection has an impact on the levels of operational discharge through deterrence. Reductions in routine discharge with 50% increase after automatic identification system (or AIS, ship detection using satellite navigation signals) on stream in 2008. Same approach used as for cleanups of major accidents but scaled further by ratio of regular discharges (37K tons p.a.) to major spills (29K tons p.a.).
Option 2	2% of cleanup bill x 3 for discharge volumes	EUR 8.64M	As Option 1, but with increased percentage due to modelling contribution.
	Equivalent of 2% cleanup bill x 3 for discharge volumes	EUR 11.02M	Main advantage here is modelling of the effects of major spills. Reductions in routine discharge with 50% increase with AIS on stream.
Option 3	2.25% of cleanup bill	EUR 9.72M	As Option 1, but with further increased percentage due to more sophisticated modelling contribution (as with downstream).
	Equivalent of 2.25% cleanup bill x 3 for discharge volumes	EUR 12.4M	Main advantage here is modelling of the effects of major spills. Reductions in routine discharge with 50% increase after AIS on stream. Some additions for inputs to broader ocean circulation studies.

Note: The multiplication by a factor 3 (x 3) comes from an estimated ratio of social impacts to cleanup costs of about 3 to 1.
Source: Whitelaw *et al.*, 2004.

Other studies point to similar conclusions. For example, a possible 1% increase in oil spill containment and cleanup efficiency in the New England region would yield a savings of USD 7.5 million over ten years, and nearly USD 100 million for the entire United States over that same period (Adams *et* *al.,* 2000). As new quasi-operational systems are put in place using space-based imagery (in Canada and Italy but also in many other countries), with surveillance mechanisms added (*e.g.* deterrent aircraft patrols), one may be able to obtain better cost-efficiency measurement of the overall information and surveillance system.

With regard to future satellite navigation systems, NAUPLIOS (2002-04) was a pilot project of the 5th Research Framework Programme of the European Union, and managed by the EU Directorate General for Energy and Transport. The project's objective was to demonstrate the added value of the GALILEO positioning and search and rescue services for maritime transportation of goods and hazardous materials. One lesson learned concerns the role of satellite communications in the overall information system. Satellite communication faces two main drawbacks in comparison with VHF – costs and time delivery delays. It also, however, provides the great advantage of confidentiality in data exchanges. As to costs and benefits, it was found that use of GALILEO positioning and search and rescue services would also bring benefits in terms of avoided costs (*e.g.* oil spills and ecosystem degradations). In particular, total shipping accident costs leading to oil spills and other polluting could decrease – depending on scenarios with different levels of implementation – by 1% (1st scenario), 5% (2nd scenario) and even 10% (3rd scenario) (Table 6.10).

Finally, a 2004 report for NOAA on the value of snow information examines the potential benefits of setting up a dedicated monitoring system (Adams *et al.*, 2004). Snow imposes both economic costs and benefits on society, and these effects are significant in size relative to other weather phenomena. There is also value in using current information on snow coverage, snow pack water potential and other snow metrics in human decision making. Finally, improvements in the accuracy and lead time of snow metrics such as snow coverage, depth and water content could in particular improve individual and public decision making. Although the authors noted that a comprehensive costs/benefit study was not possible due to the lack of information (especially the costs of snow information services), several sector-level estimates of the economic impacts (benefits and costs) of snow and related winter events were provided (Table 6.11). The main conclusion of the study was that the value to society of a snow monitoring and reporting system would likely be substantially greater than the costs of this system (see also Stewart, Pielke and Nath, 2004).

Other promising valuation techniques (real options and portfolio)

Several methodologies come from the finance sector that are rather promising for a number of applications: the real options and portfolio methodologies. They are briefly discussed below.

Table 6.10. **NAUPLIOS project: Costs and benefits of GALILEO's added value**

Search and Rescue services for maritime transportation of goods and hazardous materials, 2004

Present value (2008)		Costs and benefits of GALILEO's added value in European waters (EUR 1 million, prices 2004)	
Costs :			
● **Investment costs**		**102.00**	
– Shipping industry		100.63	
– National Maritime Coordination Centres (NMCC)		0.06	
– Maritime authorities/ National Disaster Coordinating Council (NDCC)		1.31	
● **Replacement, maintenance and exploitation costs**		**21.36**	
– Shipping industry		20.28	
– NMCC		0.04	
– Maritime authorities/NDCC		1.03	
Total costs:		***123.36***	
	Scenario 1	**Scenario 2**	**Scenario 3**
Benefits:			
Total decrease in accident costs	1%	5%	10%
– Less costs resulting from oil spills due to accidents	45.3	226.4	452.7
– Less oil spills from illegal oil releases	21.3	106.4	212.8
– Increased safety resulting in lower casualties	20.6	103.2	206.4
– Decrease in number of dead animals (birds, seals, etc.)	+	++	+++
Total benefits:	**87.2** and +	**436.0** and ++	**871.9** and +++
Net present value (benefits minus costs)	***–36.16 and +***	**312.64 and ++**	**748.54 and +++**
Benefit/cost ratio (benefits/costs)	***0.71***	**3.53**	**7.07**

Note: National Maritime Coordination Centres (NMCC) co-ordinate in most countries the civilian use of maritime patrol and surveillance assets. In the first scenario it is assumed that the total accident costs will decrease by 1%, in the second scenario by 5% and in the third by 10%.

Source: Maréchal *et al.*, 2004; ECORYS Transport, 2004.

The real options methodologies seek to uncover and quantify a project's embedded options or critical decision points. Adapting real options may yield interesting economic information about complex programmes, especially in organisations characterised by large capital investments, along with much uncertainty and flexibility (Teach, 2003). Although not used for space applications, recent experiences from the oil and gas, mining, pharmaceuticals and biotechnology industries indicate that this type of analysis provides valuable results (Archer and Ghasemzadeh, 2007). Companies in those industries also have plenty of the market or R&D data needed to make confident assumptions about uncertainties. Plus, they have the sort of engineering-oriented corporate culture that is not averse to using complex mathematical modelling (Reach, 2003). With real options, a number of constraints are

Table 6.11. **Examples of the economic impacts (benefits/costs) of snow and snow events in the United States**

(2004 dollars)

Economic benefits of snow	Winter tourism	Exceeds USD 8 billion/year in New England and Rocky Mountains
	Cold water fishing	Exceeds USD 2.3 billion/year in New England
	Snow pack water storage	Up to USD 348 billion/year in western United States
Economic costs of snow	Snow removal	Exceeds USD 2 billion/year for United States
	Road closures that cause lost retail trade, wages and tax revenue	Exceeds USD 10 billion/day for closures in eastern United States
	Flight delays	USD 3.2 billion annually for US carriers
	Damage to utilities	Up to USD 2 billion per event
	Flooding from snowmelt	USD 4.3 billion for 1997 floods
	Cost to agriculture and timber from frost and ice	Up to USD 1.6 billion per ice storm

Source: Adams *et al.*, 2004.

identified that are relatively useful when looking at space projects and derived applications:

- Budget constraints with fixed project costs.
- Logistical constraint, with mutually exclusive projects and other rigid interdependencies, such as follow-up projects.
- Positioning constraints help ensure that the composition of the portfolio is aligned with strategic requirements (*e.g.* starting a minimum number of projects in different technological or geographical areas).
- Threshold constraints to help ensure that the performance of the portfolio and its constituent projects fulfil minimum requirements (*e.g.* the aggregate net present value may have to exceed a minimum acceptable level).

Value remains in the eye of the beholder

A space-related service may bring substantial benefits or not, depending on a person's position in the value chain. For a direct end-user, the space application could be providing a solution, such as enhanced productivity. For a technician, it is piece of commodity equipment. To a financial officer, a space application may represent an overhead that needs to prove its worth. To a retailer, it may represent revenue.

A key variable in most CBA analysis is the choice of a "benefits denominator". Selected either as a preliminary educated guess (*e.g.* satellite data bring X% of benefits) or as a calculated average of the estimates provided by experts (*e.g.* PricewaterhouseCoopers' GMES study, 2006), or using a dedicated group contingent valuation method, the final number often remains contentious.

It is also very rarely directly attributable solely to satellite data, but instead most likely relates to a full information system or to derived services from this information system. As an example, the RISK-EOS study (2005) mentions that 20% of the flash flood casualties in Europe could be avoided thanks to the development of an information system using satellite-based data; such a system would also improve by 1% the efficiency and profitability of offshore production, resulting in gains in the range of EUR 340-840 million per year.

A great deal of literature considers how to assess the value of geospatial information in general, and types of weather information in particular. As mentioned by many users over the years, the value of earth observation, particularly for water management, comes mainly from providing evidence-based decision-making capabilities; it reduces uncertainty, although figures cannot always express that value. This is a problem that has plagued space-based remote-sensing activities over the past decades, since the taxpayers and their representatives are ultimately interested only in the final "outputs" of these activities.[4] According to Macauley (2004), space remote-sensing activities have not yet benefited from rigorous and consistent application of information valuation methodologies. The "value of information" approach is used to assess the marginal benefit of improved information due to better co-ordination. Filling information gaps 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.
4. The price of the next-best substitute for the information.

In other words, users – actual or potential – of derived information from space-based data may place a certain value on it, which depends on their willingness to pay for such information. That willingness is a measure of what economists call "social surplus": the value of the information in excess of the costs of acquiring it. When such value accrues to businesses, it is referred to as "producer surplus"; when it accrues to individual users, it is called "consumer surplus". Many studies point to the rather low value of information, especially if the probability of an event is either very unlikely or very likely, or if the actions that must be taken to avert its effects are minimal.

In addition, being better informed does not always translate into action, and inaction may or may not have socio-economic consequences. This has an impact on the benefits expected to be derived from space systems. With regard to the value of weather information for example, the World Meteorological Organisation (WMO) noted that the distinction needed to be made between weather-sensitive activities and weather-information-sensitive activities. In weather-sensitive activity for example, coconut trees may be affected by severe weather, such as tropical cyclones – but there may not be much that can be done to save crops. In weather-information-sensitive activities, there is normally more scope for considering actions that could have significant economic implication – *e.g.* harvesting the matured rice crop days before the predicted passage of an incoming tropical cyclone (WMO, 2003).

In the larger context, there is a growing literature on attempts to assess the costs and benefits of possible alternative courses of action for decision makers. In the OECD, a research programme on the "costs of inaction" by policy makers is ongoing, led by the OECD Environment Directorate. While considerable work has been undertaken on the costs of implementing policy in specific areas, in many cases there is inadequate understanding of the consequences of inaction; those consequences may accrue exponentially in the distant future in a number of environment-related areas. The OECD is pursuing different strands of work on this issue in three areas: biodiversity and ecosystem services; climate change; and health impacts from pollution.

The European Environment Agency also looked at the "impacts of actions or inactions" of governments in responding to "early warnings" of hazards over the past hundred years (EEA, 2002). The report, entitled *Late Lessons from Early Warnings: The Precautionary Principle 1896-2000,* focused on lessons that could be learned from past histories to minimise possible future impacts of agents that may turn out to be harmful, and to do so without stifling innovation or compromising science. Looking at government reactions in a dozen case studies over the past decades (*e.g.* radiation in the early 1900s, sulphur emissions in the mid-1980s, "mad cow" disease in the 1990s), the report drew some interesting if sobering conclusions. There seems to be "no credible way of reducing the pros and cons of alternative courses of action to a single figure, economic or otherwise, not least because of the problem of comparing incommensurables and because the pros and cons are unlikely to be spread evenly across all interest groups."

The infrastructure approach

Large amounts of space-derived data and signals have become essential elements in the efforts to monitor and manage climate change. They have also provided useful inputs to a number of public good-oriented and commercial sectors, such as water management and maritime transportation.

However, the previous sections of this report suggest that alone, cost-benefit analysis of selected space applications does not appear to offer a satisfactory basis for decision making. On the cost side, it is clearly very difficult to allocate correctly the proportion of costs related to specific operational functions. Space activities remain an intensive R&D sector with long lead times, and satellites generally carry a multifunctional array of sensors. On the benefits side, it is difficult if not impossible to single out and measure the contribution provided by the satellites, as data and signals need to be integrated with other content and equipment to be useful.

Given these obstacles, other approaches to assessing the utility of space applications need to be explored. One such approach is to consider components of the satellite infrastructure as a public good-type infrastructure and to compare them with terrestrial infrastructures. This chapter will review some basic options for delivering a space-based infrastructure, and then examine the economic role of infrastructures in general. It will then draw parallels with investment in selected infrastructures.

Reviewing options for delivering a space-based infrastructure

Historically, space-based systems have been built through public R&D programmes designed to develop new technologies, conduct research in diverse scientific fields, and provide innovative capabilities. Since the 1980s, a number of space systems and their derived applications have proved profitable investments for private actors, particularly in the telecommunications sector. Meanwhile improved space and terrestrial technical capabilities – particularly in computing power and data processing – have led to increased use of satellite data and satellite signals in numerous applications by both public and private actors.

That is where a number of space programmes present an interesting paradox, as mentioned previously: they are considered and funded as R&D programmes but in many cases act as key infrastructures delivering unique public and private services. The term "space infrastructure" is defined as encompassing all space systems, whether public or private, that can be used to deliver space-based services. Both space and underlying ground segments are included. As mentioned in OECD (2005), there are two complementary and interlinked space-based infrastructures. The first one is in essence the "front office", *i.e.* "user-oriented" and designed to provide information-related services including communications, navigation and earth observation to governments and society at large. The second is the essential enabling "back office", *i.e.* the space transport, satellite manufacturing and servicing infrastructure. The following paragraphs will mainly focus on the "front office", particularly for earth observation.

There are several options for providing an infrastructure, from outsourcing to devolution to public or private actors (Table 6.12). As stated in OECD (2005), the role of government remains key in shaping space activities, because policy makers determine the rules of the game under which space actors – notably private ones – operate. Typically, governments are major users of infrastructure, whether it is public infrastructure to deliver services to citizens or private infrastructure as an input in their activities. In most cases, public services are financed by general taxes on the population at large, and provided free of charge or at marginal cost.

Table 6.12. **Outsourcing and devolution models for the provision of infrastructure**

OUTSOURCING: Government retains overall responsibility for the provision of infrastructure, but selectively pays private companies to undertake specific operational tasks over limited periods, based on contractual arrangements:	
1. Simple contracting out	The most basic level, this involves tendering out discrete activities, such as road works or tolling management, on a case-by-case basis.
2. Design-build arrangements	A further step involves the transfer of responsibility for designing and building infrastructure, as a single package, to a private partner.
3 Public-private partnerships (PPPs)	Transfer of extensive responsibility for the designing, building, operation, maintenance and/or financing of infrastructure, as well as associated risks, to private partners over long periods, after which the project is transferred back to government.
DEVOLUTION: Transfer of responsibility for the provision of infrastructure to entities that exist specifically for that purpose. To a greater or lesser degree, the decision-making processes within these organisations are not under the direct control of elected officials. Different models of devolution include, with increasing degrees of independence:	
1. Government agencies	Public bodies that report directly to government ministries, but which typically have a more limited set of responsibilities and a higher degree of leeway with regard to operational decisions than a ministry would have. Agencies can be established both for the delivery of works and to manage funds dedicated to infrastructure.
2. State-owned companies	Companies that are organised under private company legislation and whose management is largely independent in its decision making, but which are subject to government control by way of ownership.
3. Mixed companies	Companies in which the government maintains an important ownership stake, but where there is also private ownership.
4. Private, not-for-profit organisations	Private entities that reinvest net revenues in the infrastructure asset, with management responsible before a board made up of stakeholders, which could include government.
5. 100% private owner-operators	Situations in which the infrastructure asset is the property of a private company, which therefore assumes responsibility for all aspects of its provision, based on commercial principles.

Source: Adapted from OECD, 2007c.

By going further and drawing parallels with other infrastructures, government must strike a delicate balance in devolving or outsourcing space-based infrastructure: that between the pursuit of new efficiencies and the need to oversee the maintenance and development of key public assets. Private financing of infrastructures often does not generate “new money”, since ultimately most infrastructure must be paid for by some combination of users and taxpayers (OECD, 2007c). One exception is the mostly privately owned satellite telecommunications infrastructure, which benefits from a large profitable retail market (*e.g.* television broadcasting, maritime markets for mobile satellites services). But even in that sector, development of future capabilities relies on public funding of R&D programmes with long lead times (such as ESA’s Artemis and Artes telecommunications programmes).

In the case of devolution, operational agencies may be run as purely public bodies financed by the state. [Examples include the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) in Europe and the National Oceanic and Atmospheric Administration (NOAA) in the United States for meteorological satellites.] They may also be run on a "commercial" basis, generating a substantial share (if not all) of their revenue from the sale of services. (An example here is the Antrix Corporation Limited, the commercial arm of India's Department of Space.)

In the context of tackling climate change, one important lesson learned from the previous chapters is that space-related agencies are the cornerstones for key programme choices: working with scientists, operational users of different fields and industry, they contribute to the development of major R&D and operational systems. However, as the role of space-based infrastructures (particularly earth observation) is increasing, so should the role of R&D and operational agencies, with adequate funding in their respective lines of work.

Economic role of infrastructure

The economic impact of infrastructure has been the subject of much debate since at least the 1980s, with the discussion focusing on both the direction and magnitude of effects (OECD, 2006a; 2007d). While it is possible to establish a link between infrastructure development and economic development, it is difficult to ascertain the direction of causation: does infrastructure contribute to economic development, or *vice versa* ? Moreover, there was considerable scepticism about the initial estimates of productivity gains stemming from investment in public infrastructure.

Over the past few years, however – with improved data, new methodological approaches and refinements to models – there has been much less controversy surrounding the benefits derived from large-scale infrastructures. The patterns of underinvestment in infrastructure in some countries may have something to do with the difficulties governments experience in estimating the overall long-term effects of infrastructure on the economy. Making the "right" decision regarding infrastructure development is often difficult because of the public good nature of the benefits (how much is enough, who should benefit). Moreover, the broader impact of infrastructure is clearly conditional on how efficiently it is used. Poorly managed or poorly conceived infrastructure may well generate less return. What is important to note is that the returns on infrastructure investment take time to materialise, and may take different forms.

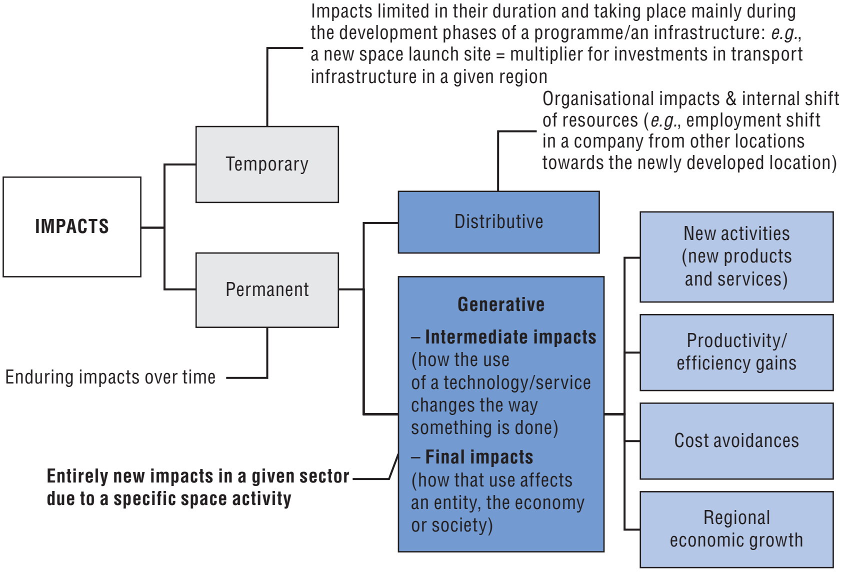
A review of the more recent literature suggests that public infrastructure has a positive productive effect on the economy, but that the size of the effect is not as large as that estimated by earlier studies. Based on samples of several OECD countries and broken down according to economic sectors, the efficiency impacts of large-scale infrastructure tend to be positive – but relatively modest – in almost all sectors. There is general agreement that road construction for example does on the whole produce economy-wide gains, but estimates vary. However, it can be said that investment in road infrastructure in OECD countries generates macroeconomic productivity effects equivalent to a rate of return of between 5% and 8%. This is certainly modest. But it has to be said that in developing countries with inadequate road networks, economy-wide productivity gains from additional road construction tend to be significantly higher. As with roads, estimates of the benefits of improving water and sanitation infrastructure vary considerably, but they are thought to be very high in the poorer developing countries.

The productive impact of an infrastructure depends not only on the magnitude of the investment, the project's design and efficient management, but also on the nature of the investment and its integration into an existing set of infrastructures, *i.e.* how it improves the network. Thus, first infrastructures only have limited impact on public and private sector productivity since their effect is primarily local. The addition of new infrastructures to create a network, however, allows considerable productivity gains by extending the use of existing infrastructures. Subsequently, when the network is largely completed, the addition of new infrastructures once again has only limited (if any) impact on private sector productivity.

From this point of view, the space-based earth observation (EO) infrastructure presents some interesting parallels. The existing systems are largely funded nationally or regionally, like other large infrastructure projects (highways, rail), and their overall impacts increase as the network of systems expands. As in the case of interconnected road networks (*i.e.* linking more users), complementary EO systems provide specific added yields, such as a greater diversity of data, back-up capacity, and improved sustainability of the overall infrastructure. Too large an expansion of the infrastructure could create fewer benefits and even some loss of efficiency (duplications). However, this is not yet the case for EO systems, although the growth of national programmes in many countries (more than 16 with EO systems in 2006) may accelerate the trend.

As previously mentioned, increased productivity is often derived from *infrastructure expansion* (*network*) and *interconnections* with other infrastructures. In the case of satellites, the notion of network is well understood; it is demonstrated by efforts made at the international level by space countries to inform other countries about their national developments and co-ordinate with them (*e.g.* CEOS and GEO). In the case of meteorology, the co-ordinating role of the World Meteorological Organisation is essential, even if nations may in some cases limit full international accessibility to their national system's weather data. The necessary interconnections with other types of infrastructure include links with *in situ* systems, which contribute unique data complementary to space-based data, and telecommunications (*e.g.* terrestrial and satellite broadband), which provide the needed links to scientific and operational users.

Figure 6.4. **Overview of general impacts derived from setting up a space-based infrastructure**



In the case of data coming from specific space systems, the question seems more crucial. The nature of earth observation systems is close to that of the traditional public good (Box 6.5). The basic characteristic of a public good is that its benefits are neither excludable (there is no way of charging for them) nor rival (one person's consumption does not reduce another's).

A number of space agencies have set up specific data policies so as to allow better access to scientific users. In April 2008 for example, the US Geological Survey announced it would gradually make all archived Landsat satellites' imagery available on the Internet for free (USGS, 2008). Today, many differences in data availability remain between countries, and different restrictions may apply (for security purposes, special licences). In addition, several commercial earth observation companies operate satellites and sell the data they collect. They are few though, and their investors and customers are often governmental bodies (Table 6.13).

A balanced approach between commercial data products – particularly the value-adding sector which facilitates end-users' access to satellite data (Wensink, 2008) – and the innate public good nature of some of the data needs to be found, possibly following the model of meteorological data. The benefits from earth observation are indeed largely the provision of knowledge, data and information that are generally considered a public good. Other typical examples of public goods are defence, and (uncongested) non-toll roads.

Box 6.5. **Definition of public good**

A *public good* is a commodity, measure, fact or service:

- Which can be consumed by one person without diminishing the amount available for consumption by another person (non-rivalry).
- Which is available at zero or negligible marginal cost to a large or unlimited number of consumers (non-exclusiveness).
- Which does not become unusable to any consumer now or in the future (sustainability). The degree of non-exclusiveness determines the public good's degree of purity.

Other definitions:

- *An international public good* (IPG) is a public good which provides benefits that cross the national borders of the producing country.
- *A regional public good (RPG)* is an international public good which provides spillover benefits to countries in the neighbourhood of the producing country, a region smaller than the rest of the world.
- *A global public good (GPG)* is an international public good which, while not necessarily to the same extent, benefits consumers all over the world.

Source: Adapted from Reisen *et al.*, 2004.

Table 6.13. **Selected commercial satellite operators in the earth observation sector**

Firms	Satellites	Status
Spot Image (FRA)	● 3 optical satellites (Spot 3, 4 and 5) ● 2010: Pleiades constellation (2 optical satellite with very high resolution 50 cm over 20x20 km) ● 2012: future high resolution sensor to ensure SPOT 5 service continuity	Mixed public-private funding (public private partnerships with CNES, DLR, etc.) EADS Astrium Services is the majority holder of both Infoterra and Spot Image
Infoterra Group (DEU, FRA, GBR)	● 1 high resolution radar satellite (TerraSAR-X, 1m over 10x10 km) ● 2009: 1 new radar satellite TanDEM-X (TerraSAR-X add-on for digital elevation measurements)	
RapidEye (DEU)	● 5 small radar satellite constellation, to be launched in summer 2008	
DigitalGlobe (USA)	● 2 optical satellites (Quick Bird and WorldView-1, allowing up to 50 cm resolution at nadir with a swath of 17.6 km) ● 2009: 1 new optical satellite (WorldView-2)	US privately-held companies, benefiting from specific US Department of Defense contracts for development and imagery (*i.e.* Clearview, Nextview)
GeoEye (USA)	● 1 high resolution optical satellite IKONOS (1 metre at nadir with a swath of 11.3 km) ● 1 new optical satellite (GeoEye-1), to be launched in summer 2008	
ImageSat (Netherlands Antilles)	● 2 high resolution optical satellites (EROS A and B, 1.9 metres at nadir with a swath of 14 km)	Netherlands Antilles company, with Israel Aircraft Industries Ltd. (IAI) as majority holder

Source: OECD/FP.

Comparative approach with terrestrial infrastructures

Arguably a key question for policy makers should be: are investments in a given space infrastructure to help meet climate change challenges inadequate, compared with investment in terrestrial infrastructures in other areas? To put the space-based earth observation infrastructure into a comparative perspective, parallels are drawn here with road and rail infrastructures, electricity infrastructures, and telecommunications (OECD, 2006; OECD, 2007b), even though some of those do not fit neatly into the public good category.

- *Road infrastructure* – Current stocks worldwide are estimated at over USD 5 trillion. Annual infrastructure investment is put at an annual USD 220 billion, equivalent to about 4.5% of world assets. Approximately 60% of that goes to maintenance and replacement, and 40% to net additions to road networks. In the coming decades the share of maintenance and replacement is expected to increase (up to as much as 80%) as stocks age and increasingly fewer new roads are built (especially in the more developed countries).
- *Rail infrastructure* – Assets worldwide are valued at some USD 630 billion. Annual infrastructure spending is estimated at nearly USD 50 billion, equivalent to around 8% of total assets.
- *Electricity transmission and distribution* – Assets worldwide are valued at some USD 3 trillion. Annual infrastructure spending is estimated at nearly USD 130 billion, equivalent to 4-5% of total assets.
- *Terrestrial telecommunications* – While this cannot be really called a public good, it is nonetheless an interesting infrastructure for comparative purposes given the ICT basis it shares with space technologies. Global stocks of telecommunications equipment (fixed and mobile) were valued at around USD 3 200 billion in 2005, and annual infrastructure investment at around USD 650 billion (splitting roughly 40/60 into new build and maintenance investment). Hence, yearly investments are equivalent to around 20% of the value of current assets, significantly higher than for roads, rail and electricity.

Table 6.14. **Estimated annual world infrastructure expenditure (additions and renewal) for selected sectors, 2005**

Type of infrastructure	Stock (USD)	Annual investment (USD)
Road	6 trillion	220 billion
Telecoms	3.2 trillion	650 billion
Rail	630 billion	50 billion

Source: OECD, 2006a.

Broadly speaking, the level of global investment going to terrestrial infrastructures over the next 10-15 years or so would appear to be increasing slightly in absolute terms but slowing as a share of GDP. This is very much consistent with the theory that as economies become more developed and networks more complete, the rate of new infrastructure added to the system declines, and the emphasis shifts from new build to maintenance. Table 6.15 provides an indication of the orders of magnitude of the infrastructure investment requirements worldwide over the next decades.

Table 6.15. **Estimated average annual world infrastructure expenditure (additions and renewal) for selected sectors, 2000-20, in USD billion**

Type of infrastructure	2000-10	2010-20
Road	220	245
Rail	49	54
Telecoms[1]	654	646
Electricity[2]	127	180
Water[1, 3]	576	772

1. Estimates apply to the years 2005, 2015 and 2025.
2. Transmission and distribution only.
3. Only OECD countries, the Russian Federation, China, India and Brazil are considered here.

In the case of the space-based earth observation infrastructure, additions and maintenance (*i.e.* fleet renewal, expanded services) and research and development (for new instruments and technologies) are the main – often overlapping – cost drivers. A clear separation between operational systems and R&D satellites is still not easily made, since the two types of satellites are complementary. Based on published observation requirements and already approved missions, a worldwide investment of roughly USD 38-40 billion, averaging USD 1.5 billion to a little over USD 3 billion a year, seems necessary for additions and maintenance in the next decade (2008-20).

Table 6.16. **Estimated annual investments (maintenance, replacement, expansion) in earth observation (2006, 2005, 2004)**

	Annual investments (in billion USD and as % of total in-orbit assets at end-2006)	
2006	3.2	15
2005	1.1	6
2004	1.6	10

Source: OECD/IFP.

The above suggests that levels of investment (annual spend as a proportion of total assets) in earth observation infrastructure are higher than those for roads and electricity network infrastructures, but close to those one would expect for expenditures on rail networks and telecommunications. Roads and rail infrastructures can have very long life spans – hundreds of years in some cases. This has to be borne in mind when comparing them with space-based assets, which have very much shorter operational lives – generally between five and ten years. Given this shorter life span, the conclusion one is tempted to draw is that the rate of replacement and expansion of the earth observation infrastructure (USD 1.6 billion in 2004, 6% of total; USD 3.2 billion in 2006, 15% of total) is relatively low compared with that for terrestrial infrastructures.

Comparative approach with terrestrial data and information infrastructure

The closest parallel with a weather information system as an information-intensive infrastructure is perhaps a country's statistical agency. The role of economic indicators – as imperfect as they may be sometimes (*e.g.* because of methodological issues) – is essential in today's modern societies. They serve as markers of the health and performance of an economy, even providing when necessary alert mechanisms.

While assets are hard to quantify, data do exist on national annual budgets to support operations. For most OECD countries, these operational budgets range between 0.02% and 0.05% of national GDP. These appear to be modest investments for statistical infrastructures that after all underpin economic and social performance.

Interesting parallels can be found when comparing national statistical offices with the budget of operational weather agencies, although they have clear differences in terms of missions (particularly for R&D).

Two examples are provided: Eumetsat and NOAA's information satellite services. The European Organisation for the Exploitation of Meteorological Satellites (Eumetsat)'s mission is to deliver weather and climate-related satellite data, images and products to the National Meteorological Services that are members of the Organisation. Eumetsat has an annual budget of around EUR 150 million to EUR 200 million (EUR 168 million in 2008), with regular peaks when developing and procuring new satellites (Eumetsat, 2008). But on top of this Eumetsat budget, major investments in European meteorological satellites come from ESA and individual EU member states, up to around 65% for the development of the space segment of a given programme (*e.g.* national R&D efforts for a specific instrument that will be carried on board the European meteorological satellites).

Table 6.17. **Budgets of various OECD national statistical offices in USD and as a % of national GDP**

	Year	Office/bureau	Estim. Budget (USD million)	% of national GDP
Australia	2005/06	Australian Bureau of Statistics[1]	243	0.039
Norway	2005	Statistics Norway[2]	77	0.031
Sweden	2005	Statistics Sweden[3]	59	0.018
Canada	2005/06	Statistics Canada[4]	528	0.052
France	2005	INSEE[5]	415	0.022
Germany	2005	Federal Statistical Office[6]	183	0.007
Italy	2003	ISTAT[7]	282	0.021
United States	2005	Census Bureau[8]	765	0.007
United Kingdom	2005/06	Office for National Statistics[9]	389	0.020

1. Revenues from government appropriations and other sources – Australian Bureau of Statistics Annual Report.
2. Total government appropriations, revenues and refunds – *Statistics Norway Annual Report*.
3. Sweden has a turnover of SEK 911 million but budget appropriations of SEK 440 million – *Statistics Sweden*.
4. Gross budgetary main estimates – Treasury Board of Canada.
5. INSEE, *Rapport d'activités 2005*.
6. Germany's expenditure for all levels of government was EUR 4.302 billion.
7. ISTAT annual budget.
8. Funding for discretionary appropriations, permanent appropriations and budget authority – *FY 2007 Budget in Brief*.
9. Gross administration budget – Office for National Statistics Annual Report and Accounts.

Source: OECD/IFP.

NOAA plays a national meteorological services role for the United States. It is in charge of setting up requirement and procuring meteorological satellites, in co-operation with NASA. NOAA's budget is around USD 1 billion for its satellite activities (NOAA, 2008). Again, funding for US meteorological satellites does not come solely from NOAA; there are other sources, particularly the Department of Defense. For example, the future National Polar-orbiting Operational Environmental Satellite System, or NPOESS programme, is funded equally by the Department of Commerce which oversees NOAA and the Department of Defense Air Force annual appropriations.

A risk management approach to investment in space-based infrastructures

To help reduce uncertainties related to climate change and so improve decision making, a risk management approach applicable to investment in space-based infrastructures is explored here. This section begins by introducing some notions about risk management and uncertainty, and then draws some parallels with weather information. Finally, it envisages systematic space-based climate monitoring as a compelling approach to reduce uncertainty.

Introduction to risk management and uncertainty

The risks to human life and economic assets stemming from the effects of population growth, economic growth, globalisation and climate change are substantial, and difficult to predict. By the time those effects are felt, they may well be irreversible. Indeed, some of the natural hazards facing society are so great in magnitude (hurricanes, earthquakes, tsunamis, droughts of continental proportions, pandemics), and the potential economic impacts so severe, that some catastrophe risks would appear to be uninsurable. A mixture of private insurance, financial market instruments and state funding would be needed to counter the dramatic losses. By way of illustration, a repetition of the 1923 Tokyo earthquake would today inflict losses in the order of one-third of Japan's current GDP (Zajdenweber, 2000).

Risk management comprises an array of methods and techniques that estimate the likelihood and consequences of undesired events, using either qualitative or quantitative methods (An example of the latter is the uncertainty or "insufficient weight of the evidence" coefficient developed by Keynes.) Those tools provide valuable if not perfect decision aids in the face of uncertainty. As shown almost a century ago by Knight (1921), one way to deal with large-scale uncertainty is to insure against a range of outcomes.

Knight's concept has been studied extensively by those developing the economic theory of insurance (see Dionne, 2000; Eeckhoudt, 2005). Insurance follows a rather basic risk transfer mechanism: premiums are paid as a mark-up over potential losses. A typical problem for insurance companies is the possibility of incurring losses above premium income, especially if independent losses add up too quickly and so produce a high aggregate loss. A possible solution is reinsurance, which pools the portfolio of insurance companies. Risks linked to climate uncertainty, however, might become too large to bear with traditional instruments. Thus, new insurance investment vehicles have emerged in the past decade; they are presented in the next subsection.

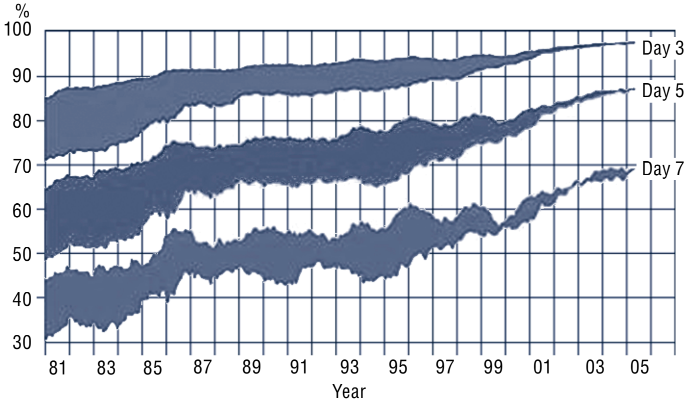
Parallels with weather information

Weather information has always been useful for reducing uncertainty and making decisions – from planting crops since antiquity to decisions on the most cost-effective energy outputs when the temperature rises in summer. Over the past decades, improvements in the ability to forecast weather have clearly had an important impact on society.

Better forecasts than ever – Today's four-day weather forecast is as accurate as two-day forecasts were 20 years ago, and the accuracy of forecasts of large-scale weather patterns in both hemispheres has been increasing since 1980. The traditional error in a three-day forecast of the landfall position of hurricanes has been reduced from about 337 kilometres in 1985 to about

177 kilometres in 2004 (SSB, 2005). This ability was instrumental in warning residents in the United States during the series of severe hurricanes in 2005. Figure 6.5, adapted by SSB (2005), shows the monthly moving average of the correlation between forecast and observed weather features for 3-day, 5-day, and 7-day forecasts. A perfect forecast is 100% (vertical axis). The accuracy of forecasts of large-scale weather patterns in both hemispheres has been increasing steadily since 1980. The southern hemisphere forecast (bottom curves), which in 1980 was significantly worse than the northern hemisphere forecast (top curves), has caught up in accuracy in recent years. This dramatic improvement has been due largely to more and better global satellite data.

Figure 6.5. **Correlations between forecast and observed weather features for 3-day, 5-day and 7-day forecasts**



Source: SSB, 2005, adapted from Simmons and Hollingsworth, 2002.

Benefits derived from weather forecasts – There are different methodologies for estimating the economic benefits of meteorological activities. They are mostly based on value of information methodologies, such as normative or prescriptive decision making; descriptive behavioural response studies (user surveys, regression models) including contingent valuation; computable general equilibrium or economy-wide models; and “market prices” to measure the benefits of private-good meteorological services (WMO, 2003; Gunasekera, 2003). Most studies focus on prescriptive models of decision making by individual businesses in particular in the agriculture sector. Stated choice studies have also been conducted to estimate the public’s willingness to pay for improved weather products, and how much people value the weather services currently provided.

As mentioned by WMO, though the economic benefit estimates currently available are still limited (in particular marginal, *i.e.* incremental benefits), they are substantial. During a major WMO 1994 conference, certain estimates given in a number of papers are still cited today in diverse presentations (Abedayo, 2006). A typical factor for the ratio of economic benefits to a National Meteorological Hydrological Service (NMHS) budget may fall in the range of 5-10. As a crude approximation, and given that the global budgets of NMHSs in 1994 was in the region of USD 4 billion, it was concluded that the global economic benefits were therefore in the range of USD 20-40 billion, although clearly this was only a broad indicative estimate (WMO, 2003).

In the United States, a 2002 report for NOAA found that the average value of weather forecast information relative to total federal spending produces an annual benefit-cost ratio of 4.4 for US households, or net national benefits of USD 8.8 billion a year (Lazo and Chestnut, 2002). This estimate does not include derived benefits in agriculture, transportation or construction, or benefits to households in other countries that rely on weather information from the United States. It was also found that in a typical hurricane season, NOAA's forecasts, warnings, and the associated emergency responses result in a USD 3 billion savings (Willoughby, 2001). Two-thirds of this savings, USD 2 billion, is attributed to the reduction in hurricane-related deaths, and one-third, USD 1 billion, to a reduction in property-related damage because of actions taken to prepare.

Table 6.18. **Selected benefit cost ratios for weather information**

Benefit ratio	Overall benefits	Source
5-10 (NMHS)	Ratio of 5-10:1 economic benefit to a National Meteorological Hydrological Service budget in 1994. Translates to global economic benefits in the USD 20-40 billion range.	WMO, 2003
4.4 (US households)	Annual benefit cost ratio of 4.4 for US households, or net national benefits of USD 8.8 billion a year (without derived benefits in agriculture, transportation, etc.).	Lazo and Chestnut, 2002, Report for NOAA
35 to 40	Using different methods, the meteorological service benefit-cost ratio in China ranges from 35 to 40; includes both public meteorological services and meteorological services for various economic sectors (survey of 1 279 experts from all types of sectors).	Zhang and Wang, 2003
0.57 (Personal users) 9 (Construction sector) 15 (Agriculture)	In 1980, Eurostat undertook cost-benefit analyses of the Meteosat programme, estimating the direct benefits in comparison with the budgetary costs, in a series of weather-sensitive industries. According to these estimates, the benefit-cost ratio was 0.57:1 for personal users and society, 9:1 for the construction industry and 15:1 for agriculture.	Cohendet and Lebeau, 1987

In Europe, Eurostat undertook a prospective cost-benefit analysis of the Meteosat programme in 1980; the goal was to estimate direct benefits in comparison to budgetary costs in a series of weather-sensitive industries.

According to these estimates, the benefit-cost ratio was 0.57 for personal users and society, 9 for the construction industry and 15 for agriculture (Cohendet and Lebeau, 1987). More recently, a detailed survey among Meteosat users in the United Kingdom also estimated these benefits (Morel de Westgaver and Robinson, 2000) and extrapolated them to the rest of the participating countries. That study found that better weather forecasting has led to substantial benefits in the air transportation industry: about EUR 11 million per year. Benefits to the agricultural industry were about EUR 30 million, thanks to the rational use of pesticides. Overall accumulated benefits for the general public reached around EUR 2.75 trillion over a period of 20 years. Meteosat also allowed a reduction in costs in the fields of transportation, energy, fishing, agriculture and the manufacturing industry of up to EUR 2.5 trillion (estimates based on declared preferences expressed in a survey).

One recurring problem, identified in previous sections, is the diversity and at times complexity of existing methods for the evaluation of benefits derived from meteorological services. This makes international and economic sector comparisons indeed challenging.

Economic importance of weather information: the insurance market – Cost-benefit analysis provides valuable data, but another way to look at the economic importance of weather information is to study insurance markets.

With regard to insuring uncertainty concerning weather, complementary mechanisms have been developed over the past fifty years. They include premiums set up by insurance companies, reinsurance, and the use of markets for risk transfer particularly via catastrophe ("cat") bonds. Weather is a major determinant of earnings performance for entire economic sectors (*e.g.* utilities). For decades, financial products based on weather outcomes have been available in most OECD countries, to transfer weather risk to counterparties in a better position to manage it (Campbell and Diebold, 2005). There are two main weather risk insurance packages: catastrophe risks and weather risks (Table 6.19). Historically, weather hedges have usually been bought by energy companies and agriculture actors. It has been estimated for instance that up to 80% of agricultural losses are linked to weather conditions (WMO, 2002).

To offer another illustration of the usefulness of weather insurance, the US Department of Transportation estimates that weather-related delays cost passengers USD 10 billion in lost time and productivity each year in the United States alone. As shown in Table 6.20, June is historically a high-delay month in the United States, and two-thirds of those delays can be related to weather events. An analysis of American Airlines' weather-related losses in 2004, which topped USD 97 million, showed that extreme weather alone was responsible for USD 1 million in losses, whereas other events averaged USD 200 000 (Anselmo, 2007).

Table 6.19. **Financial instruments for weather insurance**

Catastrophe risks (*e.g.* floods, hurricanes, earthquakes)	Weather risks (*e.g.* temperature and rainfall fluctuations)
● Low-frequency high-severity risks (unlike motor vehicle risks for example). ● Probabilities of occurrence and damage not precisely computed. Need much more data than for high frequency risks. ● Variance of loss is high. Premium setting is difficult. ● Capital requirements to ensure solvency are large. ● Premiums can be high (as high as seven times the expected losses – the actuarially fair level). ● Premiums can change drastically with an event – suggesting that probabilities of extreme events are not well established and therefore revised with any new information.	● Different types of coverage/severity depending on the sector (temperature and rainfall fluctuations with agriculture crops, storms with airline industries) ● Often the insurance package is for systemic aggregate risk but leaves out individual-specific risk ● System encouraged by the World Bank in developing countries, particularly for farmers

Table 6.20. **US airline delays accountable to weather**

	June 2003	June 2004	June 2005	June 2006	June 2007
Number of flight delays that month	27 284	44 282	39 128	32 172	41 447
Percentage of all delays that month	74.5%	77%	78%	70%	72.3%

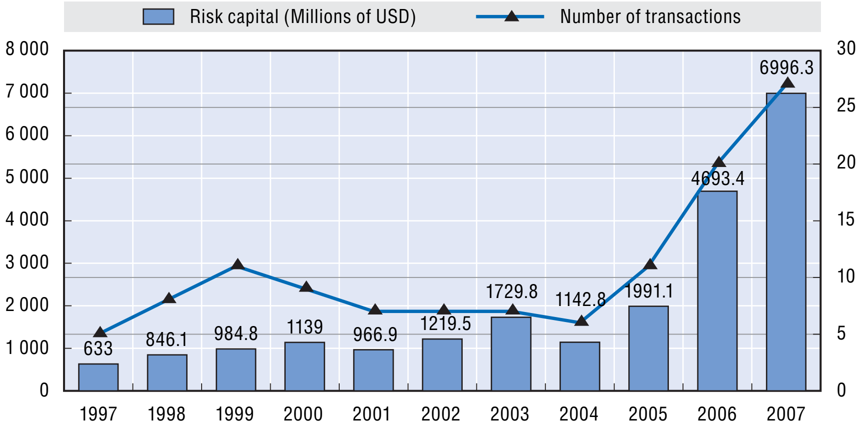
Source: US Department of Transportation, quoted in Anselmo, 2007.

With regard to climate change, the number of industries interested in the risk management approach is growing; there are new insurance customers in transport, retail, tourism and construction. New weather risk management insurance instruments, such as catastrophe bonds or "cat bonds", are also being put in place by the private sector to help industries limit their financial exposure to climate and, as shown in Figure 6.6, transfer the economic risks of catastrophes onto the international stock market. Record-setting years are becoming commonplace; 2007 was by far the most active year in the brief history of catastrophe bond issuances, following Hurricane Katrina and the 2004-05 hurricane season.

As of early 2008, the total catastrophe limit outstanding – *i.e.* the maximum amount of insurance that can be paid for a covered loss – amounts to USD 169 billion. Among the available instruments the cat bond market is becoming significant, representing 12% of estimated property limits outstanding in the United States. That country is the world's "peak" exposure zone, where theoretically capital markets have the greatest ability to absorb large losses (GC Securities, 2008; see Figure 6.7).

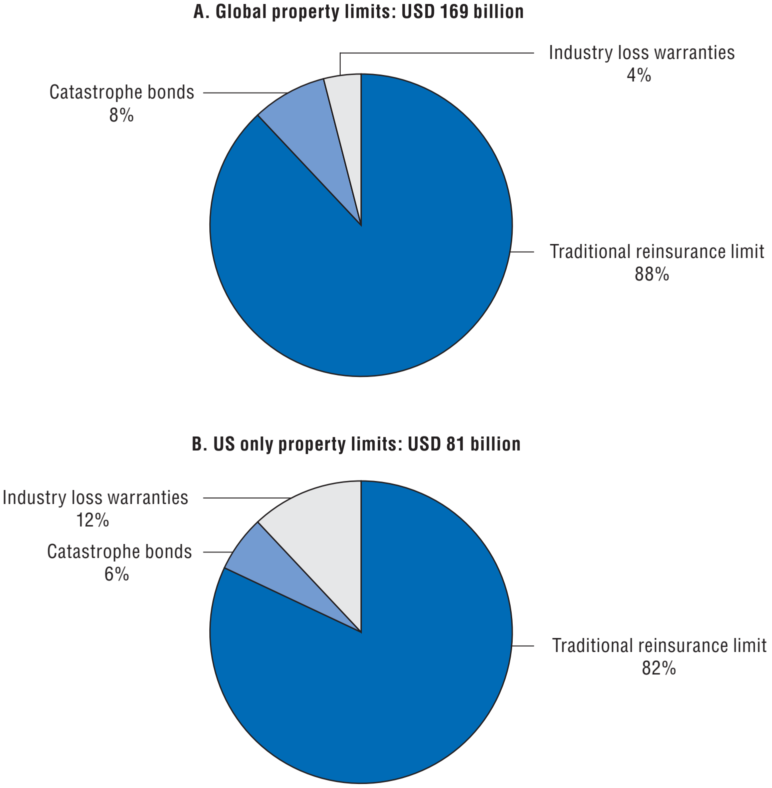
Another tool is the recently developed industry loss warranty (ILW), a financial mechanism that covers large-scale losses from events where the industry-wide insured loss exceeds some pre-agreed threshold (*i.e.* the loss is at

Figure 6.6. **Annual catastrophe bond transaction volume in the United States, 1997-2007**



Source: GC Securities, 2008.

Figure 6.7. **Limits outstanding for world and the United States in early 2008**



Source: GC Securities, 2008.

industry level rather than at company level because of a large-scale disaster).[5] Although the premiums for this type of coverage are expensive, this trend of risk transfers to markets could continue based on the expected excess demand for coverage (*i.e.* increased bond issuance) compared to supply (*i.e.* the pool of investors), and also because of the increased perception of risk due to extreme weather activity in many parts of the world.

The frequency and severity of future expected losses do cast some doubt on the financial capacity of the international insurance and reinsurance industries to absorb the costs of large-scale disasters. The development of new emerging insurance markets – particularly in China and India, countries with histories of large-scale natural hazards – could potentially place greater pressure on global markets over the coming decades. The high risk of accumulation and the difficulties in spreading catastrophic risks, geographically as well as over time, are among the main problems that insurance and reinsurance companies are facing in this field. Capital markets may provide additional sources of capacity, as shown in this section, but their role should not be overestimated at this stage (OECD, 2004).

Reducing uncertainty with systematic space-based climate monitoring

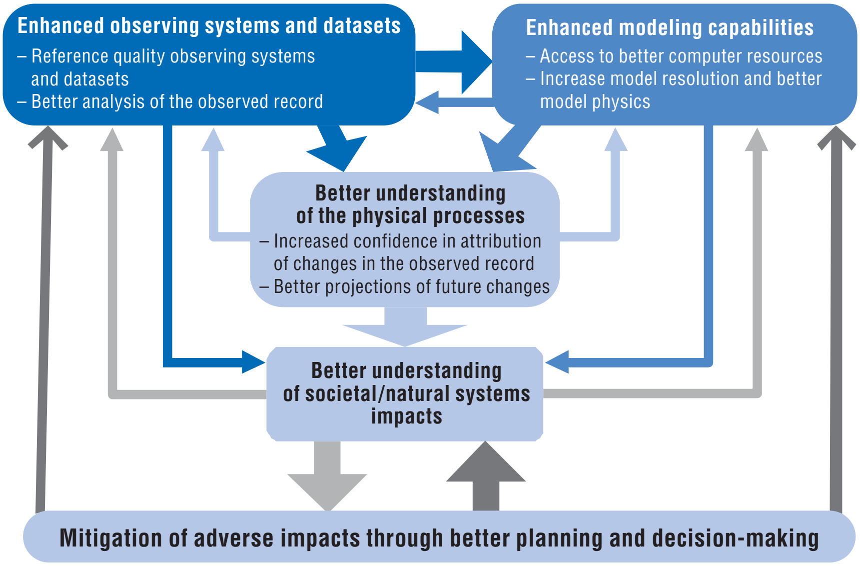
Based on the analysis conducted so far, decision makers have several options when tackling uncertainties linked to climate change:

- They can decide not to take any specific step to reduce the uncertainties identified at the beginning of the report. However, this may come at cost. Costs of inaction have already been evaluated by several organisations, all which point to important potential impacts in terms of economic growth and loss in GDP (OECD, 2008b). Moreover, those estimates may moreover well be underestimates since extreme events and non-market impacts are still often not included.
- They can rely on transfers of the risks of extreme weather events to individuals and markets, via insurance, reinsurance and capital markets (catastrophic bonds, for example). As seen in Chapter 1, insured natural peril losses have been on the rise for the past 20 years, mainly because of the increased value concentration in high-risk populated areas, higher vulnerabilities and widening insurance coverage. But another recurring factor is the notable rise in extreme weather events and the consequent effect on the ability to absorb costs mentioned above.
- They can decide to reduce uncertainties by developing the right tools to make better-informed decisions. Among those tools, space technologies – particularly earth observation – provide unique capabilities, as shown in Chapter 4. The data becoming available internationally on climate and the environment are expected to increase. However, there are still questions on

how much other key data might be *missing* if new national and international missions to replace current systems are not launched soon. This is especially true for some climate-related satellite measurements.

Improving satellite infrastructure is indeed but one of the avenues that need to be pursued to generate reliable data on climate change and its possible impacts. As shown in Figure 6.8, a better scientific understanding of the phenomena described throughout this report will only be gained by taking into account the interrelationships between better observing systems, improved analyses and modelling, physical understanding, and clearer documentation of observed patterns in climate.

Figure 6.8. **Interrelationships between inputs and components leading to better understanding of weather extremes**



Source: Based on CCSP, 2008.

As part of this climate monitoring system, a number of space technologies are making very valuable contributions to the management of the earth's resources – mapping hazards, deepening knowledge of natural phenomena, and so on. Despite the difficulty in assessing quantitatively the socio-economic benefits derived from space-based infrastructures, unique capabilities have been identified that have positive impacts on both scientific research and operational monitoring of fundamental variables and possible tipping points of climate change (*e.g.* the Arctic situation). In terms of helping to manage major risks, their contribution is multifaceted.

Thus, space-based infrastructure and its derived applications can help:

- Improve understanding of the risks.
- Reduce uncertainty.
- Reduce vulnerabilities.
- Strengthen prevention.
- Enhance the conditions for mitigation.

For space-based climate monitoring to develop as a sustainable routine activity, several modifications to existing structures must be made. As mentioned in previous chapters, space-based observations of climate variables have been relying a great deal on R&D missions, in addition to operational meteorological systems. A large number of climate variables have required – and still require – the development of dedicated new sensors for scientific research on climate processes (WMO, 2007). For many years, numerous climate observations have been made possible by R&D missions. R&D space agencies have successfully made, and continue to make, a key contribution to climate monitoring. But today this approach raises some questions.

The GCOS Climate Monitoring Principles (GCMPs) require long-term continuity of measurements, which is not the primary objective of R&D programmes. In addition to R&D activities, which are obviously required to further progress in science and technology, what is needed is recognition of climate observations as operational programmes. Already, major national and international efforts have been made in terms of meteorology. Many satellites from different countries form the space-based Global Observing System (GOS) that the World Meteorological Organisation co-ordinates, and from which key weather information is available daily to citizens and private actors. The GOS framework is based on voluntary commitments by WMO members. Building on experiences from the meteorology world, systematic climate monitoring may become an essential tool for governments to hedge the risks associated with climate change and unsustainable resources management.

Policy makers can create for themselves and the populations they serve the opportunities to be warned in advance and to better manage potential impacts. As a possible way ahead for earth observation infrastructure in particular, more attention should be given to building on major decades-long national and international efforts to develop and sustain operational satellite meteorology. For climate monitoring to develop fully as a routine activity with long-term continuity of measurements, and with induced socio-economic benefits, institutional work-sharing and adequate funding will become increasingly necessary for agencies responsible for satellite R&D activities, and the operational weather agencies will necessarily inherit new climate-related tasks.

Space infrastructure – particularly earth observation – needs to be considered as a strategic asset in an infrastructure portfolio approach, when decision makers are forced to consider their options for improved risk management.

Notes

1. The European Organisation for the Exploitation of Meteorological Satellites (Eumetsat) is an intergovernmental organisation that establishes and maintains operational meteorological satellites for 19 European States. Eumetsat is currently operating Meteosat-6, –7 and –8 over Europe and Africa, and Meteosat-5 over the Indian Ocean. The data, product and services from those satellites make a significant contribution to weather forecasting and to the monitoring of the global climate.
2. NASA was to incur costs for operating the TRMM satellite through 2007 even if the mission had been terminated in December 2004 (as planned), since it takes time for a spacecraft to drift down to an appropriate altitude for controlled re-entry.
3. The Canadian National Aerial Surveillance Programme is operated by Transport Canada, and is the principal surveillance mechanism for monitoring and enforcing ship compliance with the international MARPOL regulations (*i.e.* oil pollution at sea) covering the Atlantic, Pacific and Arctic EEZs, as well as the St. Lawrence – Great Lakes Seaway.
4. 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 the number of earth observation or weather “products” supplied – are more difficult to measure.
5. Examples of what ILWs could cover: a winter freeze with industry-wide insured loss in North America exceeding USD 20 billion; an earthquake with industry-wide insured property loss exceeding USD 35 billion anywhere in the world.

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List of Acronyms

AATSR	Advanced Along Track Scanning Radiometer (instrument on board ENVISAT)
AIS	Automatic Identification System
ASAR	Advanced Synthetic Aperture Radar
ATSR-1 and 2	Along Track Scanning Radiometer (instruments respectively on board ERS-1 and ERS-2)
BRIC	Brazil, the Russian Federation, India and China
BRIICS	Brazil, the Russian Federation, India, Indonesia, China and South Africa
CNES	Centre National d'Etudes Spatiales
CZCS	Coastal Zone Colour Scanner (instrument on Nimbus-7)
DMSP	US Defense Meteorological Satellites Programme
DORIS	Doppler Orbitography by Radiopositioning Integrated on Satellite (instrument on board TOPEX/Poseidon, Jason-1, ENVISAT and the Spot satellites)
DSC	Digital Selective Calling
EEZ	Exclusive Economic Zone
ENVISAT	ENVIronment SATellite
EPIRB	Emergency Position Indicating Radio Beacon
ERS-1 and 2	European Remote Sensing Satellites
ESA	European Space Agency
EUR	Euro (currency of European Union)
FAO	Food and Agriculture Organization
GDP	Gross domestic product
GEOSS	Global Earth Observation System of Systems
GHG	Greenhouse gases
GMDSS	Global Maritime Distress and Safety System
GMES	Global Monitoring for Environment and Security
GOES	Geostationary operational environmental satellites
GOME	Global Ozone Monitoring Experiment (instrument on board ERS-2)
GOMOS	Global ozone measurement by the occultation of stars (instrument on board ESA's ENVISAT satellite)
GOOS	Global ocean observing system
GSE	GMES Services Element

IFREMER	Institut français de recherche pour l'exploitation de la mer
IMAGE	Integrated Model to Assess the Global Environment
IMO	International Maritime Organization
IMSO	International Mobile Satellite Organization
IOC	Intergovernmental Oceanographic Commission of UNESCO
IOOS	Integrated Ocean Observing System
IPCC	Intergovernmental Panel on Climate Change
ISPS	International Ship and Port Facility Security Code
ISRO	Indian Space Research Organisation
ITU	International Telecommunication Union
LANDSAT	LAND observation SATellite
MARS	Monitoring agriculture by remote sensing
MERIS	Medium resolution imaging spectrometer [per MODIS]
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MODIS	Moderate resolution imaging spectrometer (instrument on board NASA's Terra and Aqua satellites)
MSR	Maritime search and rescue
MWR	Microwave radiometer
NEXRAD	Next generation radar meteorological stations
NOAA	National Oceanic Atmospheric Administration
NOPP	National Oceanographic Partnership Program
NRT	Near-real-time
OECD	Organisation for Economic Co-operation and Development
POES	Polar operational environmental satellite
ROW	Rest of the world
SAR	Search and rescue
SAR	Synthetic aperture radar satellite
SART	Search and rescue radar transponder
SCIAMACHY	Scanning imaging absorption spectrometer for atmospheric cartography
SOLAS	International Convention on Safety of Life at Sea and its amendments
SSAS	Ship security alert system
SSH	Sea surface height
SST	Sea surface temperature
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNESCO	United National Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
USCG	US Coast Guard
USD	United States dollar

VMS	Vessel monitoring system
WHO	World Health Organization
WMO	World Meteorological Organization
WSIS	World Summit on the Information Society
WTO	World Trade Organization

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