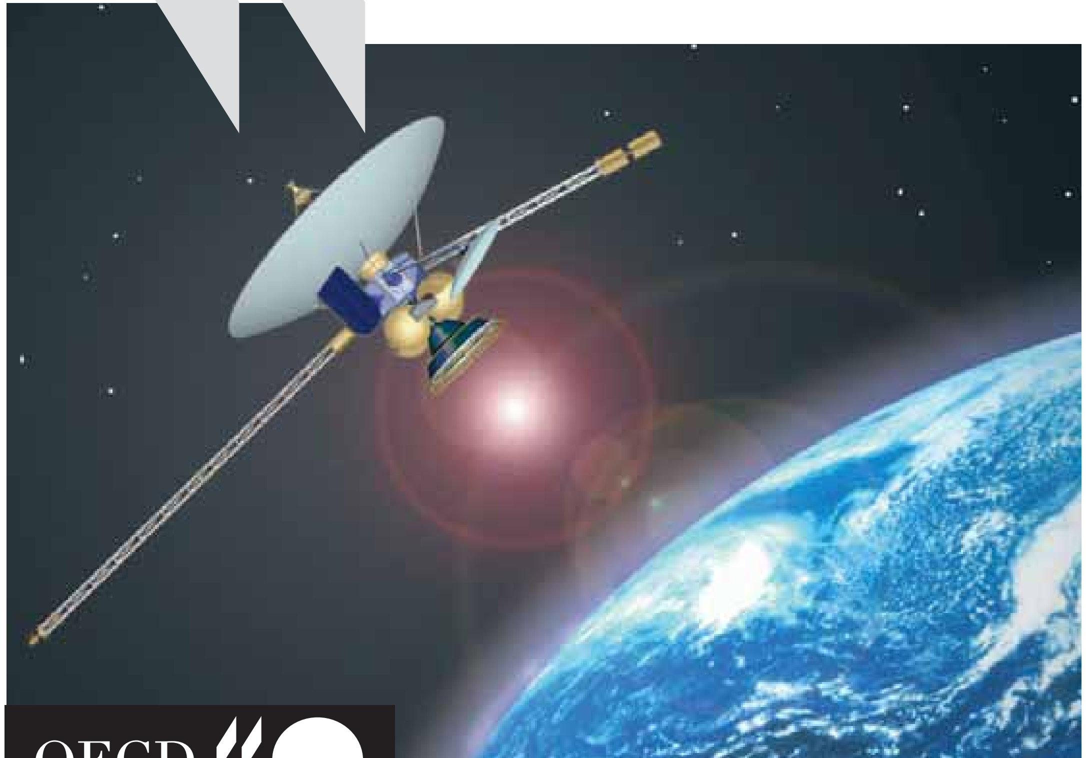
Space 2030

EXPLORING THE FUTURE OF SPACE APPLICATIONS



OECD

Space 2030

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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L’espace à l’horizon 2030

Quel avenir pour les applications spatiales ?

Foreword

Today's decision makers face a complex and uncertain world in which assessment of the trends shaping our long-term future is a major challenge. It was with this challenge in mind that in 1990 the OECD established the International Futures Programme to help decision makers in the public and private sectors come to grips with emerging issues.

The future prospects of the space sector and its contributions to the economy and society at large is one of the important issues that deserve policy attention, not only because of the sector's strategic importance but also because of the difficulties it faces and the benefits that the development of commercial and civil space applications could bring in coming decades.

In light of this and following extensive consultations with major actors in the space sector, the OECD launched in January 2003 a two-year futures project on the commercialisation of space and the development of space infrastructure, with 25 participating public and private entities.

This book is in the nature of an interim report. It reflects the work carried out in the early phase of the project. The text focuses on exploring the future evolution of the space sector with a view to identifying space applications that can be considered promising in the coming decades. The preface provides information on the purpose and scope of the project and outlines its main phases.

Michael Oborne

Director of the OECD International Futures Programme

Preface

Ever since the dawn of the space age, spectacular missions – the launching of Sputnik in 1957, the landing of Apollo on the Moon in 1969 and the first images from Mars Pathfinder in 1997 – have fired the imagination of billions of people. At the same time, disasters such as the loss of the space shuttle Columbia have made headlines throughout the world while cost overruns, delays in meeting stated objectives and unfulfilled promises have raised questions about the value of space programmes, their direction and, more generally, the benefits of space ventures for humanity at large.

However, space is not just a showroom for nations to demonstrate their technical proficiency. The deployment of space technology has contributed to an unprecedented increase in our understanding of the universe we live in, and the strategic value of space assets is increasingly recognised. Indeed, it motivates a substantial share of the efforts to develop the space sector in major space-faring nations. Moreover, the development of civil and commercial applications has had a growing impact on the lives of hundreds of millions of individuals. Lives and property have been saved through the use of satellite-based meteorological and emergency services, tens of millions of households worldwide are able to enjoy a broad choice of television offerings beamed by satellite broadcasting operators directly to their homes, whether they live in urban, rural or remote areas, and a growing number of businesses and individuals have come to rely on space-based positioning and navigation systems. As further progress is made over a broad range of space-related technologies in the coming decades, the body of potential civil space applications, both public and private, is likely to increase substantially. If properly harnessed, these advances can have a major impact worldwide, in terms both of stimulating economic growth and of responding to social and environmental needs.

Reaping the full benefits of future space innovations for society at large will not be easy. First, a growing number of nations now express interest in space for strategic as well as commercial reasons. While their efforts can help to foster the development of new applications, they can also lead to chronic overcrowding in key segments of the space market (notably the market for launching services). Second, although space technology has many potential uses, it has proved very difficult to develop financially viable applications. In particular, the transition from publicly funded activities to applications relying largely on private resources is fraught with problems. Third, as the range of commercial applications increases and as ever more countries become active in space, there is a growing need, at both national and international levels, for an institutional and regulatory environment that fully takes account of the sector's expanding commercial component (*e.g.* by providing a level playing field) and that fully supports its growth.

This situation is leading a number of countries that are already active in space to reassess their overall space strategy. Many are facing difficult choices in terms of the overall level of effort that should be devoted to space activities, how that effort should be allocated and the role that the private sector might play.

In this context and following extensive consultation with major space actors, the OECD launched formally in January 2003 a two-year Futures Project entitled *The Commercialisation of Space and the Development of Space Infrastructure: The Role of Public and Private Actors* (the Space Project). Its main purpose is to take stock of the challenges and opportunities facing space actors in order to gain a better understanding of the issues at stake and of measures that could help to ensure that the space sector contributes fully to the development of the economy and society at large.

Several factors make the OECD a particularly appropriate platform for this project. First, many OECD countries devote a significant amount of resources to space-related activities. Second, most of the key players, public and private, are located in the OECD area. Third, space applications will increasingly concern domains where OECD governments have major interests beyond their traditional responsibilities for military and scientific fields (*e.g.* security, environment, education, health, communications and transport). Finally, many of the policy issues raised by the future development of the space sector (*e.g.* regulation of markets, industrial and scientific policy, public and private governance) clearly fall within the OECD's field of competence.

The project is conducted by a Project Team in the OECD's International Futures Programme (IFP), a forward-looking multidisciplinary unit that provides the Secretary General and the Organisation with early warning on emerging issues, by pinpointing major developments and analysing key long-term concerns to help governments map strategy.

Twenty-five public and private entities are participating in and contributing financially to the Space Project. A Steering Group, chaired by Michael Oborne, Director of the IFP, provides overall advice to the Project

Team. The project is expected to be completed in December 2004, with the final report to be published in 2005. It is expected to:

- Provide an original forward-looking and policy-oriented assessment of the issues facing the sector.
- Achieve a better understanding of approaches that might be adopted to develop promising space applications.
- Raise awareness among "mainstream" policy makers and society at large of the opportunities offered by space and of the challenges facing the space sector.
- Contribute to the formulation of possible solutions that governments may find useful in addressing some of the main problems facing the sector.
- Foster international co-operation among the governments of space-faring nations across the world.

The project is being carried out in five main phases. In Phase 1, the current state of the space sector is considered and its future evolution is assessed. This provides the necessary basis in Phase 2 for the selection and grouping of the promising applications that are the main focus of attention in the rest of the project. In Phase 3, business models that might be used to implement these applications successfully are explored. In Phase 4, the regulatory, legal and institutional obstacles to implementation are examined, and measures for improving the framework conditions under which space activities take place are considered. The general conclusions and recommendations resulting from this work are to be drafted in Phase 5.

A series of interim publications and working papers are to lead up to the preparation of a final synthesis report. The present volume constitutes the first interim report. It is based on the work of the Project Team in Phases 1 and 2 and focuses on exploring the future evolution of the space sector in order to identify space applications that may be promising in the coming decades. As the work progresses, other interim reports on subsequent phases of the project may be published.

Michel Andrieu is the principal author of the present publication. He was assisted by Claire Jolly and Marit Undseth. Advice was provided by Pierre-Alain Schieb, the initiator and co-ordinator of the project, and by Barrie Stevens, who is directing the preparation of the series of reports. Manon Picard provided technical support.

The Secretariat's work benefited considerably from substantive contributions from members of the Steering Group and in particular from the European Space Agency. It also benefited from the input of leading experts in the field (see Annex C), some of whose papers are distributed as OECD Working Papers, and from the knowledge and advice of colleagues in various

OECD Directorates and Agencies, notably the Directorate for Science, Technology and Industry.

This volume is published on the responsibility of the Secretary-General of the OECD.

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Executive summary

Following extensive consultations with major space actors in 2002, the OECD International Futures Programme (IFP) formally launched in January 2003 a two-year Futures Project to explore the future of the space sector over the next 20 to 30 years. Its purpose is to understand how OECD countries may reap the benefits of civil and commercial space applications for society at large.

This first interim report describes the early phases of the project. It first reviews the current state of the space sector and the institutional, legal and regulatory obstacles to its development that have been identified by various experts in the field. This sets the scene for the future-oriented analysis conducted in subsequent chapters. A scenario-based approach is adopted to consider the future evolution of major components of the space sector and to identify applications that might be considered "promising", *i.e.* technically feasible and able to create significant net social value in either the public or the private sector.

Current state of the space sector

The growth of commercial space

In the early years of the space age, public actors played a dominant role, as the state was the only client for space products and services. The acquisition of space assets was motivated by considerations of strategy and prestige and to fulfil civil objectives (*e.g.* the pursuit of scientific knowledge). Because of the formidable technological challenges presented by the development of space applications, private actors could not reasonably have been expected to pursue business space opportunities on their own.

Despite the obstacles, the private sector expressed an early interest in space ventures, but commercial space activities only seriously began to be undertaken in the 1980s. Public space activities provided the space industry with opportunities to transfer technologies from public (civil/military) applications to commercial endeavours. This movement accelerated in the 1990s. The decline in public space budgets after the end of the cold war forced private firms to find commercial outlets for the expertise they had acquired from public contract work and to compensate for reduced public business by an increase in private sales. Commercial exploitation was made more attractive by the privatisation and liberalisation of service markets. This led to the restructuring and consolidation of the space industry, as a result of which there are now only a handful of players in the industry's key segments. Owing to these developments, the share of commercial space activities increased steadily worldwide and, in 2000, represented 65% in the United States, 50% in Europe and 30% in Japan.

The current state of the industry

After a phase of rapid expansion in the 1990s, the space industry is slowly recovering from the dot.com bubble and "the collapse of the big LEO", *i.e.* the failure of the large constellations of low Earth orbit (LEO) mobile telecommunication satellites, such as Iridium, to meet the expectations of their sponsors. The upstream component (launcher and satellite manufacturers and providers of launching services) was particularly hard hit in the early 2000s. Downstream firms (providers of space-based products and services, notably telecommunications, positioning and navigation services and Earth observation services) have fared better.

Slow recovery upstream. Launching activities remained depressed in 2003 for the third year in a row. Excluding the launch of Columbia, which was lost on re-entry, 62 launches were performed worldwide, the same number as in 2002. Satellite manufacturing faced similar problems. These were exacerbated by significant progress in terms of the durability and capacity of spacecraft, which has reduced the need for new satellites and their replenishment. The satellite industry suffered in 2001, when only 75 satellites were launched, the lowest number in the past decade and a 32% drop from the previous year. While just over 80 satellites were launched in 2002, the number dropped back to 69 in 2003 (for purposes of comparison, 150 satellites were launched in 1998). According to Euroconsult, only 19 commercial satellites were ordered in 2003 at a total estimated value of USD 2.1 billion.

However, there are signs that the worst of the downturn may be over. For instance, Arianespace returned to profitability in 2003 by cutting costs and by steering clear of unprofitable contracts. There are also signs of recovery at the space division of the European Aeronautic Defence and Space Company (EADS Space), Europe's biggest space hardware manufacturer, which has cut costs through restructuring (including widespread layoffs at EADS Astrium) and added more than EUR 600 million in telecommunications and science satellite orders to its books in 2003. Similar restructuring has taken place on the other side of the Atlantic.

In future, the launching and satellite manufacturing industry should continue to rely heavily on government contracts. The Teal Group estimates that nearly three-quarters of the 1 174 satellites that might be launched over

the next decade will be built with government funds. During the same period, only 324 commercial satellites are likely to come on stream, most of them to be launched in the second half of the decade. The military market is expected to be a major contributor to the recovery. Indeed, military contracts offer lucrative, long-term work to contractors who are seeing their commercial business dry up. This will benefit most directly the major US providers of military space equipment, as the United States accounts for 95% of the world's military space expenditures.

Uneven growth downstream. The situation looks somewhat brighter downstream, although growth is uneven. Revenues of the 36 communication satellite operators that make up the fixed communications satellite services industry, the most mature downstream component, remained flat in 2003 at USD 6.15 billion. These services represent 95% of total satellite communications revenues. While communications satellite operators have not yet fully recovered from the dot.com bubble, they have benefited from rapid progress by their main clients, the providers of direct broadcasting services (DBS), which account for two-thirds of their revenue. In fact, the world DBS industry has exploded, rising from USD 1.5 billion in 1995 to USD 22.5 billion in 2001, when more than 54 direct-to-home (DTH) platforms distributed more than 5 000 TV channels to over 45 million subscribers around the world. In 2003, revenues of the 54 companies that make up the industry rose to USD 33 billion, an increase of 27% over the previous year. The direct broadcasting of radio by satellite to moving vehicles is also proving successful in the North American market, although on a more modest scale (1.3 million subscribers by the end of 2003). Satellite broadband is an emerging application that may provide an effective solution to meeting the needs of users in rural and remote areas in the coming years.

Another market segment that is experiencing rapid growth is satellite-based location and navigation services, although only one such system – the US Global Positioning System (GPS) – is fully operational today in the OECD area. GPS has already created a substantial downstream market estimated at about USD 10.6 billion in 2001 for both hardware and value-added services. By 2010, this market may reach USD 41 billion as GPS chips are integrated in more and more products. The entry of Galileo in the second half of the decade should further spur market growth. Optimists even predict that by 2020, 2.5 billion people will be using navigation systems.

Earth observation (EO), the third main component of the downstream segment, is much smaller and struggling. While EO is one of the oldest satellite applications, commercial observation satellites (COS) are still relatively new. The industry only started up when restrictions on satellite imagery technologies were relaxed at the end of the cold war. Despite substantial technical progress in recent years, the economic prospects of COS remain uncertain in a very competitive market. In 2003 sales by the commercial remote sensing industry, including aerial and satellite segments, were estimated at USD 2.6 billion, with the satellite segment representing roughly a third of the total. By 2010 sales could reach USD 6 billion with USD 2 billion for the satellite segment.

Public space markets

While commercial demand for space products and services has grown in importance over the years, government still represents a major market for the space industry. Indeed, following the downturn in commercial activities since 2000, they have regained their leading position. In 2001, world public budgets for space activities were estimated at about USD 38 billion, they rose to USD 43 billion in 2003 and may exceed USD 50 billion by 2010. In 2003, about 57% of public space resources were devoted to civil applications (USD 24.3 billion), with the remaining 43% (USD 18.5 billion) allocated to military space programmes. By the end of the decade, military space budgets may reach a level similar to those of civil programmes for the first time since the end of the cold war.

Particularly significant for the future of the space sector is the expected growth and reorientation of US public space budgets. The US military space budget is expected to rise from USD 17.5 billion in 2003 to an estimated USD 25 billion in 2010, a 40% increase. Under President Bush's new space exploration plan, announced on 14 January 2004, NASA's budget should also grow, although more slowly (at 5% a year for the next five years), and may reach USD 18 billion by 2010 (USD 16 billion in 2004). At the same time, funds are expected to be substantially reallocated – from the space shuttle (to be retired by 2010) and the ISS (to be completed in 2016) to exploration missions and the development of a crew exploration vehicle. The more modest European consolidated space budget (EUR 5 billion or USD 6.2 billion in 2003) should also expand, but at a slower pace, and reach some USD 8 billion by 2010. Rapid growth is also expected in the public space budget of major Asian space-faring countries, notably China and India, although from a much lower base.

These developments are good news for the space industry, since it is estimated that about 70% of public space budgets are contracted out to private firms in one form or another. Another important development in recent years is the greater role played by private capital in funding government ventures for which public institutions have little room to manoeuvre. This provides governments the financial flexibility to establish programmes of a scale unachievable with public funds alone. Seven space projects have already been started under a public-private partnership (PPPs), six are in Europe and

include Galileo, the largest PPP to date at a cost of EUR 3.2 billion (excluding operating costs).

Framework obstacles to future growth

Many experts believe that, in addition to technological and economic challenges, space actors also face a number of institutional, legal and regulatory obstacles that slow the sector's development and may even threaten the existence of some companies, including major ones. The main obstacles that have been identified include:

- ***Market access restrictions:*** Despite the liberalisation brought about by the World Trade Organisation (WTO) Agreement on Basic Telecommunications Services in 1997, the liberalisation process remains incomplete.
- ***Procurement policy:*** While the public sector represents the industry's main market, governments are not always reliable and predictable as customers and partners for industry.
- ***Export controls and investment restrictions:*** Such restrictions create uncertainties, result in losses of markets and prevent efficient industry restructuring.
- ***Spectrum allocation problems:*** Despite the efforts of the International Telecommunications Union (ITU), frequency allocation and usage as well as mitigation of interference are increasingly difficult areas.
- ***Obstacles to the development of new applications:*** Governments accord insufficient attention to the development of commercial space, but their attitude is crucial in light of the enormous technical and market risks faced by private firms.
- ***Legal and regulatory constraints:*** Because the basic principles of international law were established in a context of public law, their application to the business world requires substantial interpretation. This is a source of uncertainty for industry. Moreover, various regulations fragment markets, raise costs and unduly delay the deployment of applications.

Exploring the future of the space sector

General approach

A scenario-based approach, largely based on methodology developed by the Rand Corporation, was used for an analysis of the demand side because of the long time frame adopted in the study. It involves: *i)* constructing appropriate scenarios that provide alternative visions of the future evolution of the world; *ii)* sketching out the consequences of each scenario from a political, economic, social, energy, environmental and technology perspective; and *iii)* drawing the implications for the future evolution of the main components of the space sector and for future demand for specific applications.

To construct the scenarios, four main drivers of change were considered: geopolitical developments, socio-economic developments, developments related to energy and the environment, and technology. They were selected both because of their importance for the future evolution of world events and because of their importance for the space sector.

Outside experts in these areas were invited to prepare "driver-specific" background papers offering a scenario-based assessment of the future evolution of the world. They were asked to spell out the consequences for the space sector and to draw implications for the future development of space applications from this perspective.

The driver-specific background work provided the basis for the analysis presented in this report. First, three synthesis scenarios were constructed, using as a starting point the driver-specific scenarios developed by the experts. The implications for the future evolution of the three main components of the space sector (military, commercial and civil space) were then considered and space applications that could be considered "promising" were identified.

The synthesis scenarios

The three synthesis scenarios constructed on the basis of the background reports are: *smooth sailing* (a relatively optimistic scenario); *back to the future* (a middle-of-the-road scenario); and *stormy weather* (a relatively pessimistic scenario).

Scenario 1: Smooth sailing. This scenario points to a global world order under the benevolent guidance of international organisations, where free markets and democracy gradually become the acceptable universal model for national institutions. Major contributing factors include the growth of global trade and the internationalisation of production worldwide. Other significant trends are progress in transport and communications and growing interest in global issues. In a favourable economic climate, co-operation among nations contributes effectively to the solution of world problems, including the alleviation of poverty. Even in this scenario, however, all is not rosy. Various groups that feel left out or oppose the existing order on ideological grounds resist what is perceived as a "westernisation" of the world. Organised crime continues to be active, taking advantage of a more open world. Both groups have access to weapons of mass effect (WME) and use them to blackmail the more vulnerable governments. Moreover, the environment continues to deteriorate – although less than in the other scenarios – despite efforts to curb

greenhouse gas (GHG) emissions. In this respect, the European Union spearheads the preparation of a post-Kyoto binding agreement that paves the way for a stabilisation of emissions towards the end of the period.

Scenario 2: Back to the future. In this scenario, three major economic powers dominate the world: the United States, Europe and China. The United States remains the main power for a while but its leadership position is gradually eroded because of its relatively lacklustre economic performance. It is challenged by a rapidly growing and increasingly confident China, which rejects Western values and is eager to regain, with the support of the Chinese diaspora, its historical status of "middle empire", which it considers its rightful place in the world. Russia plays an important supporting role, as Russian authorities also tend to be alienated by Western criticism. Europe remains an economic giant, but it is introverted and its institutions remain weak; the extension of the EU to 25 member countries has considerably slowed integration efforts. In the face of the assertive coalition of China and Russia, Europe chooses to strengthen ties with the United States and to co-ordinate its military forces. This leads gradually to a bipolar world, where rivalry between the two blocs dominates the policy agenda in all major spheres of activity. Tensions regarding access to energy and other resources are particularly high, as China becomes a major importer of energy and food.

Scenario 3: Stormy weather. Strong disagreements among major powers lead to a gradual erosion of international institutions. In response to sharp criticism of its interventions on the international scene, the United States becomes increasingly isolationist, withdraws from all military action not justified by a threat to American vital interests, and decides to deploy an anti-ballistic defence system to protect the US territory against limited ballistic attacks. Ethnic conflicts multiply, leading to massive migrations and terrorism. A growing number of countries acquire a nuclear capability, increasing the potential for devastating conflicts at regional level, notably in Asia and in the Middle East. Economic conditions deteriorate as the world reverts to protectionism. Growing social and ecological problems are largely ignored as international co-operation is replaced by a bilateralism driven entirely by short-term *realpolitik* considerations.

The construction of scenarios is of course somewhat arbitrary. Other possibilities might have been envisaged: the emergence of a strong federal Europe taking a leading position in a number of policy areas or greater co-operation between Europe, Russia and China to balance US dominance. Scenarios represent, at best, possible rather than likely futures. Their main interest lies in illustrating the implications of a broad range of assumptions about the future for the issue at hand (in this case the future of the space sector).

Implications for the space sector

The three synthesis scenarios presented here provide very different visions of the future world. They range from the optimistic outlook of scenario 1, where major advances are made to improve human conditions in a spirit of international co-operation, to the dark picture depicted in scenario 3, where the world is caught in a vicious circle of violence and where most of the major problems facing humanity today (conflicts, poverty, malnutrition, diseases, environmental degradation) worsen. Yet even the optimistic scenario is not without its darker side, with the rise of non-state actors increasingly capable of using WME in the pursuit of their cause, whatever it may be.

Despite these differences, the scenarios share some common ground in terms of their impact on the space sector.

Military space plays an important role in all three scenarios, although in different degrees. Even in the relatively peaceful world of scenario 1, security concerns are high and several countries are anxious to strengthen their military space capability. There is therefore robust demand for military and dual-use space assets worldwide and increases in military and dual-use space R&D budgets outside the United States are substantial.

Civil space also varies from one scenario to another, but its role is again important in all cases, albeit for different reasons. In scenario 1, it helps to foster international co-operation to solve world problems (education, health, environment). In scenario 2, prestige projects and attempts to increase soft power lead to spectacular ventures to the Moon or to Mars. Space is also applied to solve world problems but in a less co-ordinated, more fragmented and less effective manner. Even in scenario 3, the outlook for civil space is not bleak, although the level of resources devoted to it may be relatively low: as in the other scenarios, the development of dual-use technologies is a priority, and prestige and soft power are also important drivers. Application to world problems is more fragmented than in scenario 2, but may be encouraged if space firms are able to demonstrate that space solutions can actually bring about major savings for cash-strapped governments.

Commercial space varies much more across the scenarios. It thrives in scenario 1, remains strong in scenario 2 but is seriously constrained in scenario 3. However, for space firms in Europe and the United States, scenario 2 may be the most favourable because of the protection it offers against competition from non-Western firms. In all three scenarios, commercial space benefits from military space budgets.

Identifying promising space applications

The approach adopted for identifying promising space applications is essentially qualitative. It consists first in exploring the implications of the scenarios for potential demand for space applications, and then in examining supply-side considerations to assess the possibility of meeting this demand. On the basis of this "reality check", a list of "promising" applications, *i.e.* applications that are likely to be both in demand and technically feasible in the coming years, is established. The concept of demand is a broad one. It takes into account private or "commercial" as well as civil demand. Moreover, future military demand is also considered to the extent that, as in the past, technology transfer from the military may have a strong effect on the feasibility of civil applications in the coming decades. Finally, the analysis also factors in the possible existence of terrestrial alternatives to space-based solutions that may compete in the same markets.

Five different sectors of applications are considered: telecommunications, Earth observation, positioning and navigation, tourism/adventure and space production (manufacturing and in-orbit servicing).

Telecommunications: Telecommunication services are expected to be in high demand over the period in all three scenarios. However, the relative importance of specific demand components (military, civil, commercial) varies. The relatively strong role of civil and commercial space in scenario 1 paves the way for space-based solutions to social problems and the bridging of the digital divide. By contrast, in scenario 3, the demand for telecommunication services by the military tends to dominate. In scenario 2, the various components of demand are more balanced. The most promising applications in telecommunications may be telemedicine, distance learning, e-commerce and multimedia entertainment.

Earth observation: The demand for EO services is expected to increase in all scenarios, with different demand mixes. As for telecommunication services, military demand is likely to be stronger in scenarios 2 and 3 than in scenario 1. Civil and commercial demand should be stronger under scenario 1. Applications to strengthen domestic security (including measures dealing with natural and man-made disasters and extreme weather conditions) should be important in all scenarios.

Positioning and navigation: Under all three scenarios, the demand for positioning and navigation services is expected to be strong. Again, the composition of demand may vary, and military demand is likely to be strongest in scenarios 2 and 3, while commercial demand should be greatest in scenario 1. More rapid development of infrastructure in scenario 1 should create strong derived demand for space-based positioning services by the construction industry and urban planners. Likewise, expected increases in traffic should generate substantial growth in the demand for navigation services and location-based services.

Space tourism/adventure: This application involves taking paying customers to space on an orbital or suborbital flight. Tourism is one of the world's largest and fastest growing industries, and space may be the next destination of choice for the very adventurous tourist. The development of space tourism very much depends, however, on technological advances (notably the cost and reliability of space travel) and the economic climate. It thus only fully develops under scenario 1. In scenarios 2 and 3, a general environment of distrust and the dual nature of launchers strongly limit space tourism's commercial possibilities.

Space production: This areas includes in-orbit servicing, in-orbit manufacturing (testing and manufacturing of pharmaceutical products and new alloys in microgravity), space power generation (development of space solar power systems to provide energy from space to Earth) and extra-terrestrial mining (*e.g.* mines on the Moon). Prospects for these activities are highly dependent on a reduction in the cost of access to space and a favourable climate for private enterprise in space. Demand for most activities is low in all three scenarios, except for space relay satellites with possibly relatively high demand in scenario 2 as the ability to transmit energy via space could contribute to increasing the security of the energy supply.

In terms of technical feasibility, a number of the applications identified as promising are likely to become even more attractive in terms of costs and services provided, although some may face increased competition from terrestrial alternatives. This is essentially the case for information services such as telecommunications, Earth observation and location-based services that will be little affected by changes in the cost of access to space. On the other hand, the technical feasibility of space tourism, in-orbit servicing and power relay satellites is more doubtful, as it will critically depend on the future evolution of the cost of access to space.

Introduction

This report considers the current situation of the space sector and explores its evolution over the next 20-30 years with a view to identifying "promising" space applications. The analysis is based on the expectation that the world environment in which the space sector will evolve will be largely determined by a number of the main drivers of change that have shaped world events and the sector in the past and are likely to continue to do so in the future, namely geopolitical developments, socio-economic developments and technology. Moreover, new concerns, relating notably to energy and the environment, can be expected to play a key role as well.

At first blush, any attempt to explore the future of the space sector may appear to be an impossible task. Indeed, when looking back to the surprises and tragedies of the recent past, one may feel that any attempt to peer into the future is essentially futile. However, it is also clear that it is impossible today to take a strategic decision without a vision of the future environment in which the consequences of such a decision are likely to be felt. For instance, it would be highly irrational to build a new car, a new airplane or a new launcher without a fairly good idea of its potential use and the revenue streams it is likely to generate.

To address this difficulty, which confronts decision makers daily all over the world, it is useful to take a close look at the past. With the benefit of hindsight, one often finds that past events that took everyone by surprise at the time might indeed have been anticipated if more attention had been given to major trends and causal factors. Some of these may be "inevitable surprises", *i.e.* forces or trends that are "inevitable" because they already exist and have sufficient momentum to unfold inexorably for a significant period of time. However, while inevitable, such trends may still be full of surprises. This is because, although the basic events are largely predetermined, the timing, the results and the consequences are not (for more details on inevitable surprises, see Schwartz, 2003).

When looking at the past, it is easy to find examples of such "inevitable surprises". For instance, it should have been clear to most experts in the 1970s that the Soviet Union was on an unsustainable course and was bound to collapse sooner or later. However, one could not have anticipated when this would happen or what form it would take. When looking into the future, population ageing represents an interesting type of inevitable surprise. For instance, we know today that the age composition of the population of many OECD countries will change drastically over the next few decades as average populations get older. This will cause a sharp increase in dependency ratios, putting huge pressures on existing welfare regimes. However, we do not know how public concern about this problem will evolve, what actions governments are likely to take as a result, and what may be the consequences for the economy and society at large.

This is where scenario work comes into play. By making appropriate assumptions regarding the major uncertainties that will influence future events, it is possible to formulate alternative visions of the future, *i.e.* alternative ways in which particular trends or factors may play out. Each scenario represents a point on the map of possible futures. It represents at best a possible rather than a likely future. However, taken together, such scenarios can provide useful guidance for actions that need to be taken today and in the future to steer events towards a more desirable outcome and/or to formulate appropriate contingency plans. For instance, in the case of population ageing, governments can try to steer events towards a more favourable future by starting to implement pension reform now. Individuals can protect their future standard of living by starting to save towards retirement today.

In what follows, Chapter 1 considers the current situation in the space sector and reviews some of the main issues facing space actors today. This sets the scene for the future-oriented analysis presented in subsequent chapters. Additional details are to be found in Annex A, which brings together official and unofficial estimates of the space sector and of its impact on the economy. Chapter 2 explains how the scenarios used to explore the future evolution of the space sector have been constructed by looking at some of the main drivers that will shape the future space environment. As noted above, these drivers include geopolitical developments, socio-economic developments, developments related to energy and the physical environment, as well as technological developments. In Chapter 3 the scenarios briefly sketched out in Chapter 2 are fleshed out and their implications for the main components of the space sector, namely military space, civil space and commercial space, are drawn. Finally, Chapter 4 uses these sectoral results as a basis for considering how various types of space applications are likely to fare under the different scenarios.

The work presented here is based on four "top-down" background papers that were drafted in summer 2003 by outside experts and have been issued as OECD Working Papers. They are:

- Bouchard, R. (2003), "Commercialisation of Space, Technology Trends".

- Hertzfeld, H. and M. Fouquin (2003), "Economic Conditions and the Space Sector".
- Kane, T. and M. Mowthorpe (2003), "The Space Sector and Geopolitical Developments".
- Macauley, M. and D. Chen (2003), "Space Resources and the Challenge of Energy and the Environment".

In addition, a fifth "bottom-up" paper, focused more specifically on space applications, was used in the analysis and is also available as an OECD Working Paper:

- Peeters, W. and C. Jolly (2003), "Evaluation of Future Space Markets".

Reference

Schwartz, P. (2003), *Inevitable Surprises: Thinking Ahead in a Time of Turbulence*, Gotham Books, New York.

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Space 2030
Exploring the Future of Space Applications

Chapter 1

The current state of the space sector

To date, government has largely determined the evolution of the space sector, although the commercial segment took on greater importance in the 1990s in the aftermath of the cold war. The highly cyclical space industry is gradually recovering from the severe downturn of the early 2000s, which was largely due to the bursting of the dot.com bubble. In the medium term, public markets should be the industry's main engine of growth, because the strategic value of space is increasingly recognised in the OECD area as well as in Russia and in a number of emerging space-faring countries, such as China, India and Brazil.

Introduction

This chapter takes stock of the current situation and main components of the space sector to set the scene for an exploration of the sector's future in subsequent chapters. Particular attention is paid not only to the industry itself but also to the central role of the state and to various obstacles currently facing space actors.

On the supply side, the space sector is defined as embracing all public and private actors involved in providing space-enabled products and services. Those actors are part of a long value-added chain composed of two main components:

- The upstream component, which includes manufacturers of space hardware and providers of launch services.
- The downstream component, which includes operators of satellites and providers of space-enabled products and services.

A third group of actors, space agencies, plays a major role in both components. They conduct a large share of upstream and downstream R&D and also sometimes act as operators of space systems.

On the demand side, the space market has two main elements:

- The institutional market, which procures space assets for reasons ranging from scientific investigation and manned space flight to basic public services and the underpinning R&D. Budgets are reasonably stable globally, although priorities have changed over time.
- The commercial market, for which private or semi-private firms provide space-based services or space-enabled products to other firms or end users. The three main components of this market are telecommunications (fixed and mobile services), Earth observation (EO) and location-based services (LBS). The development of this market has depended on institutional markets; in the absence of institutional demand, for example, the commercial launcher/satellite market would probably not exist.

The following discussion first provides background information on the main characteristics of space activities, the use of space as a policy instrument, the levers that governments can use to implement space policy, and trends and factors that have shaped the past evolution of the space sector and are likely to continue to influence its development in the coming years.

This serves as the basis for considering the current situation of the industry's upstream and of the downstream segments. Next, the current policy debate and the state of public space markets is examined. The chapter ends with an overview of some of the obstacles to the further development of the sector that have been identified in recent publications.

Background

Key characteristics of space-based activities

Certain characteristics of space-based activities have important consequences for the industry's structure and institutional framework and for its development over time. Among the most noteworthy are the role played by R&D and the mastery of new technology, the importance of economies of scope, the dual nature of space technology, a typically long gestation period for the development of space assets, the long value-added chain from upstream to downstream companies, and the significance of economies of scale in the downstream segment.

R&D and the mastery of new technology: Satellites were used to explore and exploit space even before personal computers (PCs) were developed, yet the sector continues to face awesome technological and scientific hurdles that require intensive efforts in terms of R&D. Because the necessary investments carry high risk, they often require government assistance or have to be carried out by the public sector. High levels of R&D also imply significant economies of scale in space activities and important spillovers that may be captured by others. In addition, given the complexity of the technical challenges involved, a reputation for reliability and "learning by doing" play a key role in many space applications (it is commonly held in the launching business that "the more you launch the more you sign, the more you sign the more you launch").

Economies of scope: Space technologies are related to technologies used in the more broadly defined aerospace sector, and space applications are often closely associated with terrestrial technologies to provide end-to-end services. Hence, it makes sense to associate space activities with technically related or complementary activities such as aeronautics and telecommunications. This makes it possible to mitigate market risks and can allow companies to raise capital more easily. However, when economies of scope are large, they may help to create significant barriers to entry in major industry segments (*e.g.* launchers).

Dual nature of the technology: Because space technology often has both military and civil applications, the state has a strong interest not only in fundamental space research, but also in developing certain space assets and in creating a healthy national industry able to ensure rapid technological progress. From an economic perspective, however, the military side of the

equation presents some drawbacks. First, it is more difficult for a firm to take advantage of economies of scope when some of its activities involve military work, since certain information and technology may be classified and cannot be shared, even within the firm. Moreover, strategic concerns may discourage international technology transfers and the internationalisation of the industry. Finally, support for "national champions" may create endemic oversupply in segments of the space sector considered strategic by many space-faring nations (*e.g.* manufacture of launchers and spacecraft).

Long gestation and durability of space assets: Because developing space assets is a lengthy and costly process, it requires long-term financing. Private financiers are naturally reluctant to fulfil this need, as space orders are small and production runs typically very short, so that the manufacture of space assets must often rely on public support. Moreover, because the life of space assets is quite long once they are deployed (*e.g.* a communications satellite typically lasts 10-15 years), it is not possible to adjust supply quickly to changing demand conditions. As a result, the industry tends to be highly cyclical. The problem of oversupply is exacerbated when space-faring nations attempt to keep national champions in operation, for strategic reasons, even when the companies involved operate at a loss for substantial periods of time.

Long value-added chain: Space technology is essentially a transversal technology which can be used over a very broad range of areas in which the space segment, although essential, is often very small in terms of value. This makes for a very long value-added chain in which upstream companies are rarely able to capture, through vertical integration, a significant share of the productivity gains they generate. This creates a dichotomy between the upstream and the downstream components of the sector: depressed conditions in the upstream segment may co-exist with healthy growth downstream.

Economies of scale downstream: By and large, space-based services are global or cover very large regions. Their main strength is their ubiquity, *i.e.* their ability to serve customers over vast territories, irrespective of population density and political boundaries. In particular, unlike many terrestrial technologies, they do not face the problem of "bridging the last mile", *i.e.* they can provide services as cheaply in sparsely populated as in urban areas. Moreover, by using spot beams, satellites can concentrate on the most lucrative geographical markets, adjusting their coverage as these markets evolve. Hence, the larger the market, the more effective space-based solutions may be. It follows that such services benefit particularly from market liberalisation, interoperability and standardisation of requirements and equipment.

The space sector and the state

Since the dawn of the space age, space activities have been largely shaped by governments. They still play a major role today and will continue to do so in future. Hence, in order to fully appreciate the situation of the space sector, it is essential to take account of governments' perception of space as an instrument in the pursuit of their overall objectives and of their strategy for deriving maximum benefits from space applications in a changing world.

Space as a public policy instrument

Typically, governments see space as a tool to support a broad range of public policy objectives. These include defence and security, environmental policies, the pursuit of scientific knowledge and economic development.

National sovereignty: Space systems offer governments the means to reduce their dependency on information provided by foreign national space assets.

Defence and security: Space systems enable civil and military authorities to: *i)* collect and provide tactical and strategic information on a continuous basis worldwide; *ii)* broadcast information and communicate anywhere in the world; and *iii)* provide navigation assistance and guidance systems. These tools can be used to prevent and manage crises as well as to monitor treaties and other international agreements.

Environmental policies: Space systems can be used to monitor climatic conditions and environmental pressures (*e.g.* overpopulation, desertification, use of water resources, deforestation); and to manage natural disasters (*e.g.* anticipate natural phenomena such as hurricanes and provide tools for managing relief efforts, assessing damages and facilitating compensation procedures).

Pursuit of scientific knowledge and exploration: Space research and exploration contribute to improving our understanding of the universe, including the search for the origin of life and the unification of the fundamental laws of physics.

Economic development: Several space applications have already had a significant economic impact. They include:

- *Telecommunications*: Space can be a powerful tool for direct-to-home (DTH) delivery of information, including TV broadcasting and broadband services. Space can also be used to collect information from dispersed terrestrial entities (*e.g.* network of franchisees or subsidiaries of multinational enterprises [MNEs], monitoring of meters).
- *Navigation:* Space-based navigation devices facilitate the management of mobile fleets (*e.g.* trucks, ships, taxis), improve the regulation of air and rail traffic, and assist individuals with navigation tasks.

- *Earth observation*: Remote sensing can play a role, for example, in the design and implementation of new land infrastructure, the management of crops and natural resources, and the enforcement of agricultural policy and environmental treaties.
- *Meteorology*: Meteorological satellites help to improve weather forecasting and to anticipate extreme conditions and take appropriate mitigating action.
- *Development assistance*: For developing countries, space assets can offer ways to better manage their natural resources and extend services to their populations (*e.g.* telemedicine, distance education, telecommunications, broadcasting), particularly in remote areas. Although these space-based services require the deployment of appropriate ground equipment, they can be extremely valuable when terrestrial infrastructures are not fully developed.

While space can help to fulfil several policy objectives, these may not always be fully consistent. Tensions may arise, for instance, between strategic and economic objectives. On the one hand, governments want a strong space industry to support national security objectives. On the other, they want the industry to remain national or to be shared with close allies and they therefore discourage broad international alliances. They are also concerned about the transfer of strategic technologies and commercial applications of dual-use technologies. Dealing with such tensions is not always easy and often requires a difficult and complex balancing act.

Space as a target of public policy

To ensure that space makes its full contribution to meeting public policy objectives, governments can use a number of policy levers to shape the sector's development. First, they largely determine the direction of space-related R&D, and their procurement policies strongly affect space activities. Second, the laws, rules and regulations they implement have a major impact on the behaviour of space actors.

The role of governments in determining the direction of R&D and the development and operation of civil and military space-based systems has been a central one. For civil activities, governments have created space agencies with a broad mandate on space-related matters. The major space agencies generally involve themselves with basic research and the development of space systems and major space assets (launchers, satellites). They then transfer to other entities the operation and exploitation of these systems and assets. For instance, the European Space Agency (ESA) has transferred the exploitation of launchers, communication and weather satellites to dedicated organisations: Arianespace, Eutelsat, Inmarsat, Eumetsat. In the United States, NASA indicated its intention, as far back as 1996 under its Consolidated Space Operations Contract (CSOC), to delegate responsibility for space assets and their operations to the private sector.

In terms of procurement, governments had full control of the space sector for a long time, as they were its only customer. Although this is no longer the case, the public market still represents a major, if not the single most important, market for the space industry. The impact of a public procurement policy depends very much on the approach taken by public officials. For example, they may feel that public technical experts are in the best position to determine how to proceed and can develop detailed technical specifications for a product to be obtained from the private sector. This procedure makes sense for most research, but it has been criticised when used beyond the R&D stage on the grounds that it encourages contractors to take a passive "cost-value" approach in order to mitigate technology development costs and the schedule risks that the procedure imposes upon the private suppliers.

At the same time, governments are customers of existing commercial infrastructure and services. For instance, private satellite communication services can be used to provide public services such as distance education and telemedicine (*e.g.* the provision of healthcare to British and US armed forces). Governments also act as customers of commercial observation satellites (COS). For instance, in 2003 NGA (The National Geospatial-Intelligence Agency), formerly known as NIMA (US National Imagery and Mapping Agency), awarded two separate three-year contracts – one to Space Imaging, LLC, headquartered in Thornton, Colorado, and valued at USD 120 million and one to DigitalGlobe, Inc., headquartered in Longmont, Colorado, and valued at USD 72 million – under a procurement known as Clearview. The ClearView contracts guarantee a minimum amount of purchases to the providers of high-resolution imagery over three to five years. A new single licence procedure allows NGA to share this imagery with all potential partners (military, intelligence, diplomatic, allied nations and coalition partners, federal civil agencies, law enforcement and first responders), as the objective is to spur more demand from federal and local institutions.

In addition, the NextView procurement mechanism allows NGA's early participation in the next generation of commercial imaging capabilities. Nextview moves beyond the commodity-based approach of commercial imagery acquisition and seeks to ensure NGA access, priority tasking rights, volume and broad licensing terms from the next series of high-resolution US commercial imagery satellites. The agency is not buying a satellite, but is helping to finance the R&D in exchange for specific data purchase conditions. Following a competition, DigitalGlobe won out over SpaceImaging a NextView contract for over USD 500 million to build a new satellite to be launched in 2006. There are, however, political discussions concerning ways to maintain a certain level of competition for future commercial systems.

Governments also play an important role by implementing laws and regulations that govern the space activities of private actors. However, they do not have a completely free hand. National laws and the activities of private actors that they govern should be in line with obligations arising from international law as regards outer space. In particular, space activities may be the only area for which governments have agreed to be directly liable for the actions of their citizens. International space law consists mostly of rules laid out in multilateral agreements or "Conventions", including the Space Treaty of 1967, the Rescue Agreement of 1968, the Liability Convention of 1972, the Registration Convention of 1975 and the Moon Treaty of 1979.

At national level, a few countries have introduced substantial national space legislation (*e.g.* the United States, the United Kingdom, Russia). The United States' space legislation framework is by far the most comprehensive and may represent an interesting indication of what may happen in other space-faring nations as their commercial space sector expands. National legislation regarding export controls on sensitive technologies also has a major impact on the space industry's ability to serve international markets.

At international level, management of radio-frequency spectrum and geostationary satellite and non-geostationary satellite orbits plays a critical role. These common resources are not unlimited, and the increased use of space for communication purposes has created the need for regulation. The right to use a particular frequency is determined at national level within the context of an evolving legal regime established at international level by members of the International Telecommunications Union (ITU), a branch of the United Nations. This regime is codified through the ITU Constitution and Convention, including the Radio Regulations.

Main trends and factors in the development of the space sector

A broad range of trends and factors has shaped the supply of and demand for space-related goods and services in recent decades, as well as the structure of the space industry. A consideration of these factors is important for understanding the current state of the sector and also provides a useful starting point for assessing its future evolution.

Geostrategic factors

The end of the cold war: The decline in East-West tensions and the end of the arms race between East and West led to a significant reduction in military budgets in the first half of the 1990s and to lower demand for military space hardware (*e.g.* from 1991 to 1996, the US military space budget declined from 0.25% to 0.15% of GDP). In the United States, an important consequence has been the consolidation of the space industry, which is now dominated by two major prime space contractors, Boeing and Lockheed Martin. The lowering of tensions also offered unprecedented scope for greater international co-operation, notably between the United States, Europe and Russia.

Growing recognition of the strategic value of space: The end of the cold war has not meant "the end of history". National sovereignty concerns, the protection of citizens, prestige and the projection of "soft power" are still major motivations for most governments. In this context, a growing number of countries, including all of the major future geopolitical actors (the so-called BRIC countries: Brazil, Russia, India and China) are recognising the strategic value – as well as the strategic threat – that space represents as space technology becomes increasingly sophisticated. This is motivating many non-space-faring countries to try to acquire a space capability. Established space-faring nations, for their part, are reassessing their space strategy in light of the changing geostrategic environment with a view to increasing their emphasis on security and on the competitiveness of their industry in key technologies. However, only countries with vast resources and at the leading edge of technology can hope to become major space-faring countries. Others are forced to adopt a niche strategy and co-operate intensively with others.

The growing emphasis on security raises serious concerns regarding the militarisation of space and the interpretation of international law in this regard (notably Articles III and IV of the Space Treaty of 1967). A major bone of contention is the interpretation of the terms "peaceful use" and "peaceful purposes". Some argue that military activities can never be peaceful and should be completely prohibited in space. The other interpretation, which is becoming more and more consensual, is that military uses are permissible when they are not aggressive. However, this interpretation would be difficult to apply to a space asset that is an integral part of an aggressive weapon system.

Economic factors

Globalisation, liberalisation and privatisation: Since the end of World War II, there has been a general trend towards increased liberalisation of trade and capital movements worldwide, which has accelerated following the end of the cold war. In the space sector, two instruments have played a key role in recent years: the World Trade Organisation (WTO) Agreement on Basic Telecommunications (ABT), signed in 1997, which considerably liberalised telecommunications markets, including space communications; and the US Orbit Act of 2000, which has triggered the privatisation of certain major international space organisations. These trends have given a greater role to the private sector, opened new market opportunities and created pressures for restructuring and for the creation of new international space consortia. Given the ubiquity of space services, space solutions have benefited considerably from market liberalisation.

Economic development: In recent decades, economic progress has resulted in a gradual shift towards knowledge-based economies, in which a growing share of income is devoted to information-intensive goods and services as well as to leisure activities. At the same time, the movement of individuals and goods has increased significantly, causing a rise in the demand for information, transport and navigation services. These developments have benefited related space-based services (*i.e.* satellite communications, global navigation systems and Earth observation). However, the highly cyclical space industry has suffered from the current economic slowdown, notably from the bursting of the dot.com bubble.

Social/political factors

Reduced public interest in space: Once Apollo had met its objective and the space race ended, the general public generally lost interest in prestige space ventures and came to consider space flights as routine. Although spectacular missions or events briefly spark interest from time to time, there is a widespread scepticism about the value of space activities among the general public and many governmental circles, hence limited support for space-enabled solutions to specific problems and for space programmes more generally. Space activities are often perceived as expensive, risky and offering limited benefits compared to terrestrial alternatives. However, the value of space applications for security, safety and disaster control and for reducing the digital divide is increasingly recognised.

Demographic trends in developing countries: Population growth calls for the rapid development of health and education services in developing countries where the public terrestrial infrastructure is weak. This should, in principle, generate interest in space-based solutions, particularly in the larger ones. In this regard, India is an interesting case in point and is attracting the attention of other countries in Asia, Africa and Latin America. However, institutional and cultural factors have often slowed the implementation of space applications.

Environmental factors

Growing concern about the environment has sparked greater interest in tools (including space-based ones) for monitoring changes in environmental conditions and the application of environment-related international treaties, for facilitating the management of natural resources and for providing assistance in dealing with environmental crises (*e.g.* the Johannesburg Summit). The development of meteorological satellites has also greatly improved our ability to anticipate changing weather conditions, and extreme weather conditions in particular, and thus to save lives and property.

Technology

Progress in space technologies and complementary technologies (*e.g.* microelectronics and communication technologies) has opened the door to new applications with strong potential value in both the commercial and the public market. However, terrestrial technologies have sometimes displaced satellites from certain markets (*e.g.* fibre optic cables have largely displaced satellites for long distance voice telecommunications and cell phones have relegated satellite phones to a niche market). Moreover, failure to achieve a substantial reduction in the cost of access to space has slowed the sector's growth and postponed the development of other applications once considered promising (*e.g.* space manufacturing).

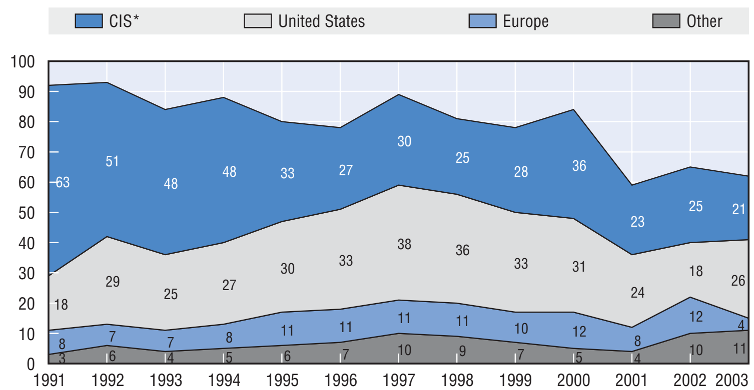
In future, the factors outlined above are likely to continue to play a key role in the evolution of the space sector. They will therefore need to be looked at when considering the sector's future development.

Current state of the upstream segment

Launchers and launching services

While the launching market was quite buoyant in the 1990s, the demand for launching services has drastically declined since 2000 as a result of cyclical factors and unfulfilled expectations (Figure 1.1). The bursting of the dot.com bubble affected space communications, the largest space applications market, as it did other segments of the telecommunications market. Another disappointment for the industry has been the failure of the large constellations

Figure 1.1. **World launches, 1 January 1991-31 December 2003**



* Commonwealth of Independent States.
Source: European Aeronautic Defence and Space Company (EADS).

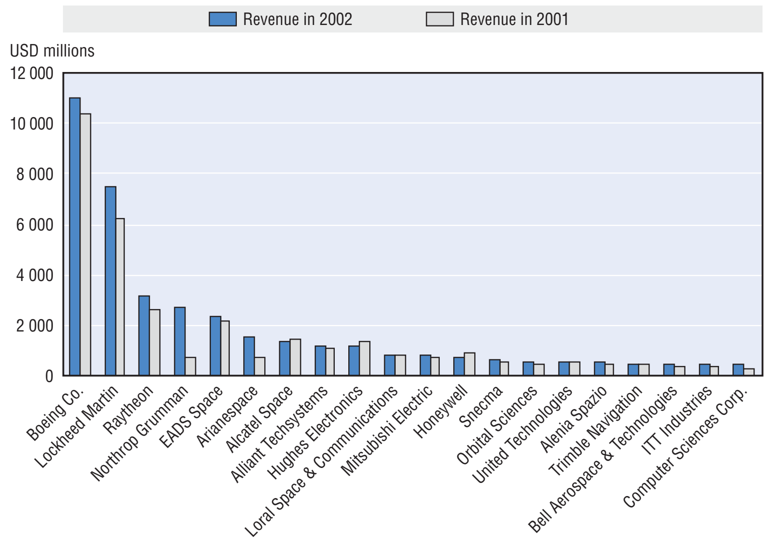
of low Earth orbit (LEO) mobile telecommunication satellites such as Iridium to meet the expectations of their sponsors.

In 2001, only 60 launches were attempted worldwide, the lowest number since the early 1960s and a decline of 30% compared to 2000, the largest single year decline for at least ten years. Business has not improved much since: there were only 65 launches in 2002 and 63 in 2003 (including Columbia which was lost on re-entry).

Despite the drop in business, the supply side has not cut back. On the contrary, new launching capacity is coming on stream and leading to serious overcapacity. A new generation of heavy launchers entered the market in the early 2000s, largely in response to the trend towards ever larger communications satellites and expectations raised by the dot.com bubble. It includes powerful boosters by the main actors in the sector (Figure 1.2) such as Ariane 5 (Arianespace), Atlas 5 (Lockheed Martin) and Delta 4 (Boeing), which are capable of lifting 8-10 ton payloads or more into geostationary transfer orbit (GTO). Overcapacity is putting even the leading launcher manufacturers in a difficult position.

Ariane 5: Arianespace, which has bet its future on the success of Ariane 5, was in the red for three years over the 2000-02 period, with a cumulative loss of EUR 538 million (USD 677 million). In 2001, the company is reported to have

Figure 1.2. **Income, upstream sector, 2001 and 2002**



Source: Space News, 2003.

lost USD 183 million, of which roughly one-third was attributed to the cost of returning Ariane 5 to full operation following a failed launch on 12 July 2001. The failure of the inaugural flight of the heavy version of the lifter on 11 December 2002 created further uncertainty. However, the company's situation improved somewhat in 2003. It is returning to profitability by cutting costs and by steering clear of unprofitable contracts, although only four launches were performed in 2003 (12 in 2002). The company has also received political and financial backing from ESA governments, which should allow the company to sign a 30-rocket order with European Aeronautic Defence and Space Company (EADS) Space, the prime contractor for Ariane 5. The commercial future of the company now hinges largely on its ability to correct the problem of the Vulcain 2 main-stage cryogenic engine (which was responsible for the failure of the inaugural flight of the heavy version of the lifter), and to qualify the rocket in 2004 (two qualification launches are planned), so as to be able to offer the launcher on the commercial market in 2005.

A main challenge for the European launcher, as compared to its American competitors, is Europe's much smaller institutional market. Because of this, Arianespace depends heavily on commercial success. However, in 2003 European governments (through ESA) and the European Commission indicated that an independent, cost-effective European launcher is in the strategic interests of Europe and must not be threatened by the ups and downs of the commercial market.

The European launch vehicle will face stiff competition from existing launchers such as the Russian Proton and the Ukrainian Zenit but also from the possible entry of new ones, notably the Atlas 5 and Delta 4, which were first launched in August and November 2002, respectively. However, these two heavy launchers, which were developed as part of the US Department of Defense (DoD) two-track evolved expendable launch vehicle (EELV) strategy, have had problems of their own.

Atlas 5: When the decision was made to produce the launcher, it was thought that Lockheed Martin would receive orders for as many as 19 launches a year. This assumption has proved highly unrealistic and did not take into account strong competition from medium to heavy lift launchers that were active or under development. In the initial batch of the DoD's EELV payload awards, Atlas received nine for Delta's 19. The subsequent transfer of two of the Atlas 5's payloads to Delta further increased the imbalance. At the end of 2002, the number of Atlas 5 launches was thus much smaller than Lockheed Martin had envisioned when it decided to invest USD 1 billion in the programme. In 2003 only two Atlas 5 launches were performed.

Delta 4: Delta 4 is an almost entirely new and much more powerful vehicle than previous models in the Delta family and was designed to be cheaper to build and operate. It was meant to be Boeing's future competitive presence in the heavy launch market. The Delta 4's cost structure was based on the assumption that the development costs could be spread over a large number of commercial missions. At the end of 2002, prospects looked promising. Boeing claimed to have more than 18 firm orders for Delta 4 through 2004 and more than 40 tentative orders. This should have kept the vehicle active for at least five years. However, the 30 commercial Delta 4 launches that the company anticipated did not materialise, reducing the vehicle's total expected workload by nearly 50%. This forced Boeing to remove Delta 4 from the commercial market and to write off roughly USD 550 million in July 2003.

Worldwide, several launchers, in addition to the competitive Russian launchers, could seriously challenge the three main contenders in the coming years. These include the Chinese Long March family, which is gaining market credibility as a result of the successful development of the Shenzhou programme, and India's PSLV and GSLV rockets, which are picking up missions that would have been assigned in the past to Ariane or Russian launchers. Japan's H-2A launch vehicle may also enter the commercial market once current difficulties have been overcome.

For the time being, the three main players in the commercial launch market are Arianespace, the US-Russian International Launch Services (ILS, controlled by Lockheed Martin) and the US-Ukraine Sea Launch venture (controlled by Boeing). Arianespace and ILS signed seven new commercial satellite-launching contracts in 2003. For added flexibility, Arianespace has signed mutual launch back-up agreements with Boeing Launch Services (operating Zenit) and Mitsubishi Heavy Industries, the prime contractor for Japan's H-2A rocket. Arianespace uses Soyuz as a complementary medium lift launcher, while ILS uses Proton as a back-up for Atlas.

Some declines in launching costs are expected in the coming years. This includes the use of multiple payload launch capability, split co-manifesting of payloads onto a single launch vehicle and efforts to reduce the launch vehicle to payload cost ratio. In the current highly competitive environment, cost savings should exert downward pressure on launching contract prices. However, lower launching prices are unlikely to generate much additional revenue as the demand for launching services tends to be rather inelastic.

Satellite manufacturing

The market for spacecraft is more of a franchise market than the launcher market: satellite manufacturers compete on price but also on the quality of their offerings and the features provided. This means that barriers to entry are probably lower than for launchers and that some firms may survive by concentrating on niche markets. Potential entrants in the industry include not only launch vehicle manufacturers, because of the market-level synergy between launchers and spacecraft, but also telecommunication equipment manufacturers (*e.g.* Alcatel Space), which may be well placed to integrate communications satellites into large telecommunication systems.

Like launcher manufacturers, satellite manufacturers have faced difficult times in recent years. These have been exacerbated by significant progress in terms of the durability and capacity of spacecraft, which has reduced the need for additional satellites, and by the consolidation of satellite operators.

While more than 150 satellites were launched in 1998, the number of launches dropped sharply in the early 2000s, owing to significant cutbacks in satellite orders, particularly for commercial communication satellites. In 2001, only 75 satellites were launched (60 launches), the lowest number in at least the past ten years and a 32% drop compared to the previous year. In 2002 just over 80 satellites were launched (65 launches), but the number then dropped to 69 in 2003 (63 launches). According to Euroconsult, only 19 commercial satellites were ordered in 2003 for a total estimated value of USD 2.1 billion. The "big LEO" that were launched in the 1990s (*e.g.* Globalstar, Iridium, Orbcomm) are not being replenished as originally expected. New broadband systems such as Astrolink, Skybridge, Spaceway and Teledisc have either been postponed or cancelled. In addition to the collapse of the big LEO, the cancellation of satellite orders by established geostationary Earth orbit (GEO) satellite operators facing excess capacity conditions is another cause for despondency. In response to cutbacks, the industry has been forced to reduce its labour force. All major satellite manufacturers, including Boeing, Lockheed Martin, Alcatel Space and Astrium, eliminated jobs in 2002. The adjustment seems particularly severe for Astrium which planned about 1 500 layoffs, or the elimination of 20% of its labour force.

A substantial rebound is not expected in the short term. While some new applications are in the pipeline, they are not expected to generate much in terms of new satellite orders. For instance, Internet is fuelling the development of business and commercial applications for commercial satellites. However, most companies that plan to offer satellite-based Internet services will not purchase satellites but lease capacity on assets already in orbit, at least in the medium term.

The bright spot is the military market, which will make up in part for the sluggishness of the commercial market. Military contracts offer lucrative, long-term work for contractors that are seeing their commercial business dry up. This will benefit the major US providers of military space equipment but will not be of

much help to non-US firms. In Europe, there are very few military satellites, and some are "dual-use" satellites that provide commercial services as well. However, other projects such as Galileo and Global Monitoring for Environment and Security (GMES) could sustain future demand for satellites in Europe.

Despite the gloom, there are some early signs of recovery. For instance, EADS has been able to cut costs by restructuring (including the layoffs at EADS Astrium noted above) and added more than EUR 600 million in telecommunications and science satellite orders to its books in 2003, and Alcatel Space and Lockheed Martin Commercial Space Systems were profitable in 2003.

Contracting out has been an important factor in the ability of satellite manufacturers to cut costs. For instance, it has allowed Lockheed Martin to downsize, reducing its workforce by 40% in two years. Boeing now performs little more than 50% of the work on a commercial satellite contract that it wins. This is creating new business opportunities for subcontractors who do business with several prime contractors.

Nonetheless, the recovery is expected to be rather subdued. There is now an industry consensus that earlier hopes of a steady stream of 25-30 commercial satellite orders a year has disappeared, perhaps forever. It may be that a market of 15 satellite manufacturing contracts a year is the best that can be expected. If so, consolidation of the five main suppliers can be expected in the coming years.

Space insurance

Space insurance is a critical element of the commercial satellite manufacturing and launching industries, since without access to coverage at reasonable rates, clients are less likely to acquire and launch spacecraft. The market for space insurance is a global market with a broad range of actors including satellite owners, satellite manufacturers, launch service providers, insurance brokers, underwriters, financial institutions and reinsurers, as well as various government agencies.

The main types of coverage available on the market include:

- *Pre-launch insurance* covers damage to a satellite or launch vehicle during the construction, transport and processing phases prior to the launch.
- *Launch insurance* covers loss of a satellite during the launch phase. It insures against complete launch failure as well as failure of a launch vehicle to place a satellite in the proper orbit.
- *In-orbit insurance* covers a satellite for in-orbit technical problems and damage once it has been placed by a launch vehicle in proper orbit.
- *Third-party liability and government property insurances* protect launch service providers and their clients in the event of public injury or government property damage caused by launch or mission failure.

A launch company can also act as an insurance provider to its customers by offering them relaunch guarantees, *i.e.* a guarantee that it will relaunch a customer's replacement payload in case of failure. When offering such a guarantee, the launch company typically protects itself by purchasing insurance for a series of launches, thus spreading the risk over a number of events and receiving better rates than it could obtain for a single launch.

Since the late 1980s, the insurance industry has experienced two distinct periods: a decade of steady growth from 1989 to 1999, followed by a sharp decline in the early 2000s. Contributing factors include: *i)* deteriorating economic conditions in the insurance industry in general; *ii)* the devastating effect of 11 September 2001; *iii)* a decline in commercial launch activities that drastically reduced the amount of premium income available to insurers; and *iv)* increased launch and in-orbit losses. Although there were some early signs of economic recovery in the third quarter of 2003, the overall situation remains rather bleak. Premiums are rising and capacity is expected to decline again to USD 700 million for 2003; only 23 geostationary Earth-to-orbit satellite launches were expected to seek coverage that year, compared to 27 in 2002.

Current state of the downstream segment

Satellite telecommunications services

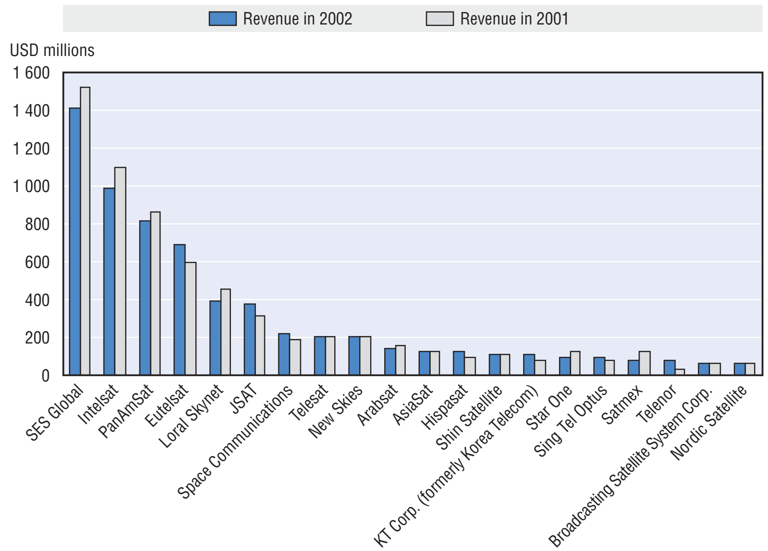
The telecommunications segment represents the largest and the most mature downstream segment of the space sector. It is made up of two main components: telecommunications and broadcasting, and a distinction is made between fixed and mobile services. The main trends affecting the industry in recent years have been the digital revolution, which is leading the various services offered to converge, and demand for increasingly sophisticated services, with growing requirements in terms of bandwidth.

The satellite operator industry

About 95% of the revenues generated are for fixed services (USD 6.15 billion in 2003 compared to USD 8.3 billion in 2001), two-thirds of which are generated by the leasing of transponders to broadcasting services, mostly DTH broadcasting services.

After years of investment in satellites and infrastructure, the satellite operator industry is currently in a process of consolidation. The unprecedented telecommunications crisis of the early 2000s has prompted the sector to focus on cost reduction and secure operations and to pursue a "back-to-basics" approach. Company concentration is steadily increasing, and the sector has enjoyed slow but steady growth over the last years, with increasing margins (Figure 1.3).

Figure 1.3. **Income of 20 biggest satellite operators, 2001 and 2002**



Source: Space News, 2003.

In 2001, six operators shared 66% of the global market: SES Global, Intelsat, PanAmSat, Eutelsat, JSAT, Loral Space and Communications. Following its acquisition of GE Americom in November 2002, SES Global is the world's leading satellite operator.

Broadband operators suffered heavily during the economic downturn as a result of a hostile financial environment and soft demand. There are, however, indications that the market is picking up again. The launch of Hughes Network Systems' Spaceway and of Shin Satellites' IPSTAR is projected for the first half of 2004. The situation of satellite mobile services is also improving. Inmarsat is still strong and Thuraya is emerging as a regional supplier of mobile satellite services. The company has just launched its second satellite and has placed an order with Boeing for a third that could be launched within two years if there is sufficient demand.

Satellite subscription and retail services – the DTH industry

The DTH industry is by far the largest segment of the industry. Its development is relatively recent. For instance, France introduced its first DTH (analog) platform, TéléDiffusion de France (TDF), to the market in 1985, while the world's first digital DTH platform (Orbit) started operations in 1994. DTH

Box 1.1. **Restructuring in the satellite communications industry**

Loral Space & Communications

The satellite communications industry is a risky business, and individual firms become very vulnerable in an economic downturn. The difficulties faced by Loral Space & Communications (Loral) in recent years offer an instructive case in point.

Loral's position in the industry is unusual in that it is both a satellite communications company that owns and operates a global fleet of communications satellites and a designer and manufacturer of satellites.

Loral has struggled over the past few years under a heavy debt burden, a problem exacerbated by the global economic downturn of the early 2000s that led to a lack of satellite manufacturing orders and a slowdown in the growth of fixed satellite services. Another contributing factor was the bankruptcy of Globalstar in February 2002, a satellite phone venture in which Loral had invested USD 1.5 billion, most of which had to be written off. By mid-2003, Loral had about USD 2.1 billion in long-term debt.

Given this situation, financial institutions were unwilling to lend the company more money. Unable to finance its debt, Loral filed for Chapter 11 protection on 15 July 2003 and was forced to put up some of its satellites for sale to the highest bidder. On 25 October 2003, a bankruptcy court approved the planned sale of five Loral satellites to Intelsat which won the bidding. Under the agreement, Loral will sell to Intelsat the Telstar 5, 6, 7 and 13 satellites currently in orbit, as well as the Telstar 8 satellite scheduled for launch in 2004, for "up to" USD 1.1 billion. The agreement also includes the rights to another orbital slot, at 77 degrees West, that had belonged to Loral but was not used. After the deal is concluded Loral will maintain five other satellites serving other regions, as well as its satellite manufacturing business.

For Intelsat, the acquisition of the Loral assets – which remains subject to Federal Communications Commission (FCC) approval and is expected to close in early 2004 – is a way to complement its global satellite network. The deal provides the company with greater coverage of the North American market and increases Intelsat's customer base in the cable and broadcasting segments.

For Loral, the sale to Intelsat allows the company to eliminate its nearly USD 1 billion in secured debt, but it forces Loral to reorganise around its remaining satellite services business, comprised of a fleet of five international satellites and Space Systems/Loral (SS/L), its satellite manufacturing business. Time will tell whether this reorganisation will be sufficient to allow the company to weather its current difficulties. There are in fact some positive signs on the manufacturing front; SS/L recently received orders to build four new satellites, one each for Intelsat and PanAmSat Corporation and two for DIRECTV, Inc.

operators have taken full advantage of the technological progress achieved upstream in satellite manufacturing and downstream in digital compression, as well as of market liberalisation in the aftermath of the WTO ABT, to compete effectively with cable operators despite high barriers to entry in the TV subscription market.

Growth has been extremely rapid. From 1995 to 2001, the world direct broadcast satellite (DBS) industry has grown from USD 1.5 billion to USD 22.5 billion. In 2001, over 54 DTH platforms distributed more than 5 000 TV channels to over 45 million subscribers around the world. Over the last two years, revenues of DTH platforms outperformed those of the box office and video games. The main market segments are movies (23%), documentary/lifestyle (12%), sports (10%) and news (8%). The success of DTH is due in large part to considerable progress in the productivity of DTH satellites over the last decade, which in turn is due to an increase in satellite longevity, in the number of transponders per satellite and in the population covered. The distribution capacity of video content for satellite has been multiplied by 187 in ten years. At the same time, the number of channels that can be distributed by each transponder has increased twelve-fold.

In 2003, the revenues of the 54 DBS operators that make up the industry grew to USD 33 billion, an increase of 27% over the previous year. Echostar was the fastest-growing provider with 1.3 million new subscribers in 2003. Satellite radio is also proving very successful in the North American market. XM, the market leader, started operation in 2001, had more than 1.3 million customers by the end of 2003 and saw its share value balloon from USD 3 in early January 2003 to USD 26 by the end of the year, a rise of more than 750%.

Interactive broadband services

Even though DBS will continue to grow and remain important, the driver for the next decade may be enhanced and interactive broadband services that can be included in traditional DTH transmission services. As DTH services become increasingly interactive, broadband and broadcast services are likely to converge and be presented in a single commercial package.

Satellite broadband has a clear advantage over terrestrial technologies: with minimal development of infrastructure, it can provide universal coverage almost immediately. However, it also has serious drawbacks: costs are very high and service is not always reliable. Moreover, because of latency, satellite broadband cannot offer services such as gaming that require a high level of interactivity. It follows that many experts view it as an interim solution for countries with a relatively under-developed terrestrial network and as filling a niche market (rural and remote areas) in countries with a rich terrestrial offering.

Estimates of the prospects for satellite broadband vary considerably and are difficult to compare. According to Northern Sky Research, there were 125 000 broadband satellite subscribers in 2002 in the United States; in 2001, 100 000 two-way users generated USD 330 million. By 2006, revenues from broadband satellite could reach USD 12.4 billion. Euroconsult considers that the number of terminals with direct access to satellite Internet (with a return line either by cable or by satellite) will grow from 350 000 in 2000 to 12.6 million in 2010. Frost & Sullivan is less optimistic. It estimates that satellite broadband has potential revenues of USD 5.1 billion by 2008 (USD 3.6 billion for the broadband direct access market and USD 1.5 billion for the Internet backbone trunking market).

In the medium term, three factors are likely to play a key role in the future development of satellite broadband.

- The industry's ability to cut costs and to mass-produce cheap, efficient and easy to use two-way terminals. It is expected that, over the next four years, new technology should enable a fourfold reduction in the cost of providing the service. At the same time, with standardisation and sufficiently large production runs, the cost of terminals could drop from around EUR 1 500 today to less than EUR 300. This should bring the cost of satellite broadband to the level of ADSL (asymmetric digital subscriber line) today.
- The industry's ability to organise itself to offer customers services of a quality comparable to that of its terrestrial competitors.
- Public support for the deployment of satellite broadband as a tool for bridging the digital divide, both within and between countries, notably to provide public services such as e-government, telemedicine and distance education. However, such support is likely to raise difficult competition policy issues.

Global positioning and navigation services

The use of satellites for location and navigation purposes is rapidly expanding, although only one system, the US Global Positioning System (GPS), is fully operational today. Originally developed by the US Department of Defense to maintain troop contact and position, GPS consists of a network of a minimum of 24 satellites launched in medium Earth orbit (10 600 miles) and regularly replenished and modernised. It proved its military value in the first Gulf war and was later made available to commercial users free of charge, but it remains under US military control. Its success in the consumer and business markets was instantaneous. GPS is rapidly becoming a standard feature in everything from search and rescue services to automobile navigation and leisure goods. It can even be used for underground work: the builders of the Channel Tunnel were one of the technology's first commercial users,

employing GPS to guide crews moving from England to France and *vice versa* to an exact meeting place in the middle. GPS has already created a substantial downstream market estimated at about USD 10.6 billion in 2001 (includes both hardware and value-added services). By 2010, this market could quadruple to USD 41 billion as GPS chips are integrated in a growing number of products.

As the use of the US GPS becomes ubiquitous and as more and more systems depend on it, there is growing concern that a disruption in the signal (whether accidental or deliberate) could have untold consequences worldwide. This has played an important role in inducing non-US space-faring countries to launch their own positioning and navigation systems. In particular, the European civil Galileo system is expected to complement and compete with GPS – in civil as well as military markets – from 2008. As a result of an agreement reached between the United States and the European Union in February 2004, Galileo and the US GPS will function in a complementary manner. By combining the two systems, users will be ensured better reliability than could be achieved with either system alone. Questions remain however, regarding the level of funding for the Galileo deployment and operational phases which are to be managed by the private sector.

Earth observation

Earth observation is one of the earliest applications of satellites (the Corona project dates back to the 1960s, and the first civil EO satellite, Landsat, was launched in 1972). However, commercial observation satellites (COS) are still relatively new. The industry started when restrictions on satellite imagery technologies were relaxed at the end of the cold war, and it has not grown as rapidly as expected. Technology has played an important role in the development of COS. In particular, advances in optical and radar sensor technologies have made possible the development of satellites that are smaller, cheaper and more agile than the original COS.

In the past, there was a relatively clear distinction between military and civil observation satellites as well as between civil and commercial observation satellites, but it is becoming less clear today as the capability of COS has increased significantly and as military and intelligence agencies increasingly rely on them. However, the economic prospects of COS are uncertain. On the one hand, there is the perception that as many countries shift to knowledge-based economies, a rapidly growing market for satellite imagery and related information products may emerge worldwide over the next few years. On the other hand, COS face stiff competition for selling geospatial information products. They have to compete first with aerial photography, which has long dominated the market and is pursuing its own innovation path. Moreover, they have to compete with land-based surveys using global navigation satellite systems (GNSS) and geographic information systems (GIS) that both compete with and complement COS imagery. Finally, international competition is likely to be fierce as new low-cost players, either state-subsidised or from emerging economies, are entering the market. Public action is thus crucial for the future development of COS.

The current policy debate

Since the end of the cold war, space has ceased to be mainly an issue of prestige and power. Space systems are being used to solve global problems, and new opportunities for international co-operation have emerged. Many countries consider space as a tool for achieving their strategic objectives.

The United States sees space as an instrument for maintaining economic, political and scientific leadership. In its 2002 report to the President, the Commission on the Future of the Aerospace Industry stressed the importance of a healthy US aerospace industry "to preserve the balance of our leadership today and to ensure our continued leadership tomorrow". The Commission also expressed concern about the concentration of the industry (five main contractors) and the greying of the labour force.

Europe. In the *White Paper on European Space Policy* prepared by the European Commission and ESA and issued by the Commission in November 2003, it is argued that a European space policy is needed to support key tasks for Europe: faster economic growth, job creation and industrial competitiveness, enlargement and cohesion of the Union, sustainable development and security and defence. A European space policy is expected to reduce dependency on non-European space systems for strategic as well as for commercial applications, to increase the possibility of a more balanced form of co-operation with the United States and to give Europe a more prominent role on the world stage.

Japan has concentrated its action in the past on programmes of considerable and immediate help to the Japanese islands in the area of communications, weather warning and marine and Earth observation. It has also used its space programmes to develop and maintain its lead in advanced communications and industrial engineering. The Japanese authorities are now increasingly concerned about competitiveness and security. In 2002, the Council for Science and Technology Policy headed by the Prime Minister, Junichiro Koizumi, proposed to streamline Japan's space budget, concentrating on programmes that enhance Japan's space industry and national security.

Russia. After a drastic decline at the end of the cold war, space budgets have recovered, but while they nearly doubled from 1998 to 2001 in national currency terms, they were halved in dollar terms. Of the estimated

USD 260 million space budget, 70% is devoted to civil applications managed by the Russian Space Agency (RKA). Facing the urgent need to replenish ageing national satellite systems, Russia uses exports of launch services to fill the gap in public financing. However, considering the level of Russian launch activities in 2003 (24 launches, including eight commercial ones, on Russian rockets, *i.e.* more than any other country), the budgetary data grossly underestimate the country's capabilities.

India attaches high priority to the acquisition of space technology for its development. This is reflected in the relatively high share of GDP devoted to civil R&D over the years (0.08% in 2001). As a result, India has become the fourth largest space power in financial terms with a budget of USD 402 million in fiscal year 2001/02, administered mainly by the Indian Research and Space Organisation (IRSO). In fiscal year 2002/03, the IRSO budget increased further to USD 500 million. Closer co-operation between India and the United States is expected in future, following the signature of a pact of co-operation between the two countries in January 2004, which could include joint production of civil satellites.

China. At current exchange rates, the Chinese space budget has been estimated at USD 150 million for civil programmes and USD 30 million for military programmes. However, these figure grossly underestimate effective spending in real terms. Some experts even believe that, with a space labour force estimated at 260 000, China may be spending in real terms, in support of ambitious space programmes, especially for human spaceflight, as much as the US National Aeronautics and Space Administration (NASA). Its efforts were crowned with success when it sent its first taikonaut into space on 15 October 2003. In 2004, China plans to launch ten satellites, while developing a larger, more capable geostationary communications satellite platform carrying 50 transponders with a lifespan of 15 years. A key question for the future is whether this intensive effort will be sustainable over the long term.

Access to space

United States: For NASA, following the Columbia accident, the main issue is the policy to adopt regarding the space shuttle and the development of an orbital space plane (OSP) for the International Space Station (ISS). Questions have been raised regarding the merit of the OSP and whether extending the shuttle's life was the best course of action. Issues have also arisen regarding the importance to be accorded to manned as compared to unmanned missions (*e.g.* deep space missions which can only use unmanned instruments) and whether programmes should stress planetary exploration or more basic physics. The Bush initiative, described below, suggests a strong emphasis on manned exploration.

On the military side, the main debate revolves around the pursuit of the dual-track EELV, which is considered expensive but necessary for maintaining guaranteed access to space, particularly at a time when there is a need to replenish and upgrade existing space assets. Meanwhile, hypersonic research has received a new boost. Both NASA and DARPA (Defense Advanced Research Projects Agency) are looking into projects on hypersonic vehicles. DARPA hopes to conduct a flight demonstration as early as 2006.

On the purely commercial side, a number of start-up companies have the ambition to provide cheaper access to space. One interesting private initiative is the X Prize, a competition started by Peter Diamandis, to award USD 10 million to the first developer of a working reusable launch vehicle (RLV). Scaled Composites' SpaceShipOne is considered the frontrunner to win the prize and reached an important milestone in December 2003 when it broke the sound barrier on a test flight.

Europe: The failure of Ariane 5 ECA (the heaviest version of Ariane to date) has forced Arianespace to review its overall strategy. The ESA Council at Ministerial level, meeting in Paris on 27 May 2003, took decisions on restructuring the Ariane launcher sector, on restoring the competitiveness of Ariane 5, and on taking further steps to prepare for future launchers. Ministers adopted measures for completing the qualification of the Ariane 5 ECA launcher so as to improve its competitiveness while ensuring the continuity of launching services through generic Ariane 5 versions and a cost-efficient back-up. The reorganisation of the Ariane launcher sector rationalises the industry by designating a single prime contractor for the launcher system for both the manufacturing and future development of Ariane 5. Arianespace remains in charge of the production phase, ensures launch operations, bears responsibility *vis-à-vis* launch customers and procures launchers from the prime contractor. Public sector involvement was also streamlined. ESA was put in charge of launcher project management, using existing competencies and the workforce in national space agencies. EAS also received a mandate to propose a reorganisation of launch operations with Ariane 5 at the Centre Spatial Guyanais so as to guarantee that European user institutions have access to space for their missions and to maximise institutional use by giving launch priority to European institutions and offering the best market prices. Ministers also decided to carry out ESA's European Guaranteed Access to Space (EGAS) programme, which covers selected fixed-cost activities associated with the production of Ariane 5, thereby putting European industry and Arianespace on a level playing field with international competitors.

Japan: On the strength of its early successes, it was hoped that the H2-A could enter the commercial market. However, following the failure of the sixth launch in December 2003 to take two spy satellites into orbit, the launcher's future is uncertain. Moreover, it still has to catch up with the new generation

of heavy boosters in the United States and Europe. Finally, time will tell how well the new line of responsibility between Mitsubishi Heavy Industries and the Japanese Aerospace Exploration Agency (JAXA) works out in practice.

Security concerns

United States: Overall security concerns have led to the creation of the Department of Homeland Security (DHS), the largest reorganisation of the federal government since the creation of the DoD in 1947. Space plays a central role in the minds of security analysts. It is perceived as a major tool for strengthening security; at the same time, it is considered a danger to the extent that other nations, including potential adversaries, are gradually acquiring a space capability that might threaten the United States. In this context, control of space, protection of US systems and the ability to attack an adversary are attracting greater attention from decision makers.

Increased US expenditure on military space assets is regarded not only as desirable from a security perspective, but also a way to cushion the slump in the aerospace industry's commercial market. Questions have been raised, however, about the strength of this cushion in future, notably whether the five-year defence programme, which calls for a 30% increase in procurement for defence, will be achieved, given that the overall military budget is expected to increase by only 10%. Some experts also argue that military expenditures could be used as leverage in trade negotiations with Europe, since the European aerospace industry has long been barred from bidding on US government contracts, including DoD contracts, which has put them at a disadvantage *vis-à-vis* US firms.

Europe has also recognised the military utility of space since the events of 11 September, and a desire to include space more closely in military planning has become evident in larger European countries. At the same time, Europe is edging towards greater overall internal military co-operation through the realisation of a European Security and Defence Policy (ESDP). However, although the need for co-operation among European countries is acknowledged, there is as yet no overarching strategy in place for Europe's military use of space. Given limited budgets for military space in Europe, interest has grown in taking advantage of the dual-use nature of space technology, *i.e.* the cost savings and efficiency gains that could be achieved from the judicious military use of multiple-use civil systems.

To achieve cost savings and efficiency gains, the United Kingdom's Ministry of Defence favours the use of private finance initiatives (PFI), to be used in its case for building a particular infrastructure for use by the military. With the Skynet 5 programme, it hopes to foster a new market for military telecommunications services worth USD 2 billion over ten years. The

Skynet 5 contract, worth GBP 2.5 billion (USD 4.6 billion), was signed with EADS on 24 October 2003. The French government is also tempted by the PFI approach. It has indicated that it may let industry handle the third and last of the Syracuse III military communications satellites, if Skynet 5 works well. The ESA/EU Galileo satellite navigation programme follows a PFI scheme for deployment and operation of the system.

Calls for increased independence have also been a major factor behind European efforts to strengthen co-operation in the development of space systems, in particular for the development of Galileo, which is perceived as both complement and competitor to the US GPS. Galileo will be partly a commercial system. A concessionaire will obtain the right to operate the system for a fixed period in return for two-thirds of deployment costs, which are estimated at some EUR 2.2 billion (USD 2.8 billion). However, control and ownership of the network will remain with the EU through a "Surveillance Authority" which will have full control over the public regulation service (PRS) to be used only by EU governments. Non-European partners (China and perhaps Brazil, India and Israel) will not have access to the PRS channel or a say in how Galileo is run during a crisis.

The European GMES initiative, even if it is mainly civil or dual-use, also reflects the fact that European governments increasingly wish to collect information independently. GMES was initially conceived for protection against and monitoring of environmental threats, but the security aspect has become more pronounced in the last year, as underlined in a resolution of the European Parliament of 29 January 2004. Moreover, limited efforts to integrate military satellite programmes are under way. French, German and Italian governments have reached an agreement on the mutual use of their respective optical-imaging systems, and other EU members have shown interest in participating in a next-generation military observation system intended to complement GMES.

Japan also has growing concerns about security, notably in relation to North Korea, and it recognises fully the value of space for security purposes. North Korean missiles have been regarded as a major security threat in Japan since 1998, when one was launched over Japan's main island of Honshu and into the Pacific. Japan has since restructured its defence budget to include a missile defence architecture based upon the US PAC-3 missile defence architecture. A Japanese Satellite Early Warning System may also be included as part of Japan's defence against the threat presented by North Korea, which led Japan to launch its first military reconnaissance satellite early in 2003.

Policy concerns raised by the current state of the industry

The depressed state of commercial space markets is forcing many firms to reassess their overall strategy. This has led to actions with significant consequences for the space sector, and which also raise important policy issues, notably regarding competition and the trade-offs between efficiency and strategic imperatives.

Exits from the industry: Faced with a slump in the market, some firms have chosen to leave the industry altogether. This is the case for instance of BAE Systems, which has decided to pull out of Astrium and Paradigm Secure Communications. Its main reason for doing so is that its substantial exposure in a number of major defence programmes makes it reluctant to indulge in additional risk taking, especially in a non-core business.

Consolidation: While some firms leave the industry, others are taking advantage of the difficulties faced by competitors or partners to strengthen their position in key segments of the space market. For instance, EADS has taken advantage of the exit of BAE Systems from Astrium to take full control of the company and rationalise its activities. This has allowed EADS to streamline its operations, notably to bring Ariane 5 launcher activities and those of Astrium within the new EADS Space group. Creating a single prime contractor for Ariane 5 is considered an important step in improving the efficiency and reliability of the launch system and making it more cost-competitive. EADS Space is a holding company currently comprised of EADS Space Transportation for launchers and space infrastructure, EADS Astrium for satellites and EADS Space Services which is responsible for developing satellite services in the telecommunications and navigation segments. EADS Space Services is also completing the formation of Paradigm Secure Communications Ltd, to manage the Paradigm programme. A cost-cutting plan is under way to restore space activities to profitability by 2004. However, decisions regarding site closures will be delicate. They will have to be based not only on business criteria but also on the need to keep institutional customers in each of EADS "core" markets (France, Germany and Spain). Moreover, the synergy between launcher and satellite production may remain limited to the extent that the two activities are carried out in separate divisions of the holding company.

Tapping new markets: The weakness of the commercial communications satellites market is forcing many companies to find alternative clients. At this time, military contracts represent the most attractive alternative. For instance, EADS expects strong growth in the military communications satellites sector. In addition to Skynet 5, EADS and Paradigm are involved in a PFI bid for NATO satellites and are pursuing similar initiatives in France, Italy and other countries. Alcatel Space is teaming up with Thales for a contract with the

French government to develop France's new Syracuse III military satellite communications system. Increased reliance on military contracts is also a fact of life in the United States. Particularly significant in this regard will be efforts to build the Transformational Communications Architecture, which will include the US Air Force's Wideband Gapfiller system and the US Navy's Mobile User Objective Systems as well as a new generation of Air Force and National Reconnaissance Office (NRO) satellites which will begin to be launched in 2012. They will be equipped with laser as well as radio frequency payloads with ten times the capacity of today's systems.

Restructuring downstream: The slowdown in the demand for satellite-based services has caused transponder prices to plunge by 40-50% during the last five years. With new services growing much more slowly than expected, operators have pared back plans for new satellites to avoid overcapacity. Concentration is taking place in the direct broadcast satellite market, given the large economies of scale that characterise DBS operations. Alliances and takeovers are likely to continue as operators seek to expand their activities and enter the broadband market. However, increased concentration is raising both competition (Echostar/DirecTV case) and sovereignty issues (Eutelsat).

Public space markets

Although the share of GDP devoted by governments to space has declined over the last decade, they are still the largest spenders on space and space budgets are rising. In 2001, world public budgets for space activities were estimated at about USD 38 billion, they rose to USD 43 billion in 2003 and may surpass USD 50 billion by 2010.

Public expenditures on space represent a major market for the space industry because they are huge in absolute value and because about 70% represents purchases in one form or another from the industry. This includes acquisition of products and services for R&D purposes, procurement of space hardware (including orbital infrastructure) and procurement and operation of launchers. Two types of public customers can be identified: space agencies, which focus mainly on R&D and therefore develop new products (the product definition is open), and institutional clients that typically acquire products off the shelf. The satellite market clearly illustrates the importance of public markets for the space industry: in 2003, government-funded missions accounted for 75% of the 63 launches performed worldwide.

Not only do governments spend large sums of public money on space, they also encourage the private funding of public ventures. In recent years, private capital has assumed a greater role in funding government ventures for which public institutions have little room to manoeuvre. Private funding provides governments with the financial flexibility to establish programmes

on a scale unachievable with public funds alone. Seven space projects have been started under public-private partnerships (PPPs); six are in Europe, one of which is Galileo, the largest PPP to date, costing EUR 3.2 billion (excluding operating costs). As of February 2004, the list of potential candidates to be considered by the Joint Undertaking for the role of Galileo concessionaire has been reduced to three. They are the Eutelsat Consortium, which consists of Eutelsat SA, Hispasat SA, Logica CMG and AENA; the iNavSat Consortium, which includes EADS Space, Inmarsat Ventures PLC and Thales SA (with SES Global and Lockheed Martin as associated partners); and the Vinci Concessions Consortium, which includes Vinci Concessions SA, Alcatel SA and Finmeccanica. All three consortia stated their willingness to finance two-thirds of the USD 2.2 billion development project. They were chosen partly on their ability to raise funding but also on their commercial approach to running Galileo and their design plans for the satellite network.

Optimists envisage that 2.5 billion individuals may use navigation systems by 2020. This could prove a very lucrative business, even if only a small fraction of users are willing to pay for the additional precision and reliability offered by the system's commercial service. Indeed, the European Commission expects Galileo to create more than 100 000 jobs and generate service and equipment contracts worth up to EUR 9 billion (USD 11.3 billion) a year, making it the continent's most lucrative infrastructure project.

World public space budgets have two main components: military space and civil space. In 2003, about 57% of public space resources were devoted to civil applications (USD 24.3 billion) and 43% (USD 18.5 billion) went for official military space programmes. However, because military budgets are rising faster than civil ones, the two budgets should reach parity for the first time since the end of the cold war by the end of the decade.

Military and civil space budgets have evolved differently in recent years. After a slight decline from 1996 to 1998, world civil space markets grew by 10% between 1998 and 2001, driven by growth in the budgets of the world's largest space actors (United States, Europe, Japan) and have at least recovered their mid-1990s levels. Military budgets declined in the early 1990s following the end of the cold war, but recovered after 1996, largely driven by renewed growth in US military expenditures. As a result, total military space budgets increased 13% between 1996 and 2001 and another 25% in 2003. However, the relative size of the two budgets varies considerably across countries. Because the United States accounts for most of the global expenditures on military space, civil space dominates space expenditures in the rest of the world.

Excluding general budget items, world civil space expenditures are dominated by three main activities: human space flights, including the ISS and the space shuttle (about 40%); space science (20%); and Earth observation, including meteorology (20%). Together, these three activities represent about 80% of all civil expenditures on space. The remaining 20% is divided among launchers (R&D for ELV), telecommunications, microgravity research and navigation.

National trends for leading countries

Although a growing number of countries show an interest in space (there are no less than 30 space agencies listed in the world, to which should be added 26 emerging programmes), public space is still dominated financially by the three main space powers: the United States, Europe and Japan. Together, they account for 95% of the world's public funding for civil space activities, and their overall share has remained roughly constant in dollar terms over the last decade. In 2003 their combined budgets amounted to close to USD 42 billion.

United States: With more than USD 33 billion allocated to military and civil space (77% of the world's total public space budget) in 2003, the United States maintains undisputed leadership. It accounts for 61% of the world civil space budget, compared to 23% for Europe and 10% for Japan, and its military space expenditures represent 95% of the world's military space funding.

A further increase in budgets is expected. On the military front, US expenditures should rise from USD 17.5 billion in 2003 to an estimated USD 25 billion in 2010, a 40% increase. On the civil front, NASA's budget should also grow in the coming years (although not as fast) and could reach USD 18 billion by 2010 (USD 15.4 billion in 2004) under President Bush's new space exploration plan announced on 14 January 2004.

For 2004, NASA's approved budget is divided almost equally between "space flight capability" (USD 7.5 billion) – essentially the space shuttle (USD 4 billion) and work on the ISS (USD 1.7 billion) – and "science, aeronautics and exploration" (USD 7.9 billion). The Bush initiative calls for a far-reaching reallocation of resources within the agency in the coming years: NASA should receive an additional USD 1 billion over the next five years and USD 11 billion should be reprioritised over the same period. Specifically, funds should be reallocated from budgets devoted to the space shuttle (to be retired by 2010) and the ISS (to be completed in 2016) to the funding of exploration missions and the development of a crew exploratory vehicle (CEV).

By the middle of the coming decade, about three-quarters of NASA's budget should be devoted to space exploration. The cumulative price tag for the new exploration programme could reach USD 170 billion by 2020. At the same time, the OSP programme (USD 15 billion) will be transformed into the new CEV programme, aimed largely at transporting astronauts beyond Earth orbit. This vehicle should be developed and tested by 2008 and conduct its first manned mission by 2014.

This new approach reflects in part a change in NASA's confidence in the shuttle following the Columbia tragedy of February 2003 and the very high cost attached to implementation of the safety recommendations made by the Columbia Accident Investigation Board. Recertification of the shuttle to fly beyond 2010 would have cost at least USD 3 billion and keeping it flying would cost about USD 5 billion a year, up from the USD 4 billion NASA spends today. Under the new plan, NASA is still expected to fly as many as five shuttle missions a year up to 2010.

The Hubble telescope, one of the most successful NASA-ESA co-operative programmes, may be the principal casualty of the changes in NASA's priorities. It is expected to cease to operate within three years, as there will be no more shuttle missions to service it and prolong its life. A decisive factor in this regard is the Columbia Accident Investigation Board's strong recommendation that NASA should be able to inspect and repair a damaged shuttle in space, an especially problematic requirement for missions not bound for the ISS.

Europe: The consolidated European space budget of EUR 5 billion (USD 6.2 billion) in 2003 is the world's second largest and represents roughly 15% of world public space expenditures. ESA, with a budget of EUR 2.7 billion (USD 3.4 billion), concentrates 55% of overall European space funding. At national level, France is the European leader with a civil space budget of EUR 1.3 billion (USD 1.6 billion) followed by Italy and Germany.

After a period of rapid growth between 1985 and 1992, both national and ESA budgets stabilised or even declined in the 1990s. In 2004, ESA's budget of EUR 2.7 billion (USD 3.4 billion) is virtually unchanged from 2003, with new investments in satellite navigation offset by decreases in spending on launch vehicles and manned space flight programmes. Launch vehicle programmes, while down from the 24% share of ESA's budget in 2003, are still the biggest single line item in the 2004 budget, accounting for 17% of the total. Manned space flight accounts for 16%, science missions for 14%, and Earth observation and navigation each take a 12% share.

In future, substantial increases in European space expenditures may result from the far-reaching review of European space policy undertaken in the first half of 2003. This review, which was formally launched by the European Commission's adoption of the *Green Paper on European Space Policy* on 21 January 2003, led to the release in November 2003 of a policy paper, *Space: A New European Frontier for an Expanding Union. An Action Plan for Implementing the European Space Policy*.

The policy paper, known as the White Paper on European Space Policy, was developed in close co-operation with ESA. It recommends measures to ensure Europe's independent access to space and to enhance space technology, promote space exploration, attract more young people into careers in science and strengthen European excellence in space science. It also calls for substantial additional spending on space and foresees a considerable reinforcement of co-operation between ESA and the EU as well as EU financing of space programmes, although some issues tied to stalled EU constitutional talks remain unresolved.

This closer link between ESA and the EU is reflected in a medium-term roadmap, *Agenda 2007*, prepared by ESA's General Director and released in December 2003. *Agenda 2007* envisages that increased investment from the European Commission will help raise ESA's spending authority by 30% by 2007, assuming that direct investments by ESA's member governments remain flat until then. *Agenda 2007* can be viewed as a stepping-stone to a long-term space programme intended to double the size of Europe's space effort.

Agenda 2007 pays particular attention to applications programmes considered crucial to Europe's strategic and economic future. These include Galileo, the deployment and operating phases of which are not yet fully funded, the GMES network and an as yet undefined satellite broadband undertaking to bridge Europe's digital divide. Another top priority will be space assets for security and defence. As part of Europe's changing geopolitical environment, these are now destined to become both an ESA and EU responsibility. *Agenda 2007* for the first time places defence squarely in ESA's domain.

Japan is world's third largest space power. In 2003, its space budget amounted to USD 2.5 billion and will remain flat in 2004. The largest share (65%) is allotted to the Japan Aerospace and Exploratory Agency (JAXA) and the second largest (23%) to the Cabinet Office.

An important milestone was the successful launch into orbit of two spacecraft in the Information Gathering Satellite (IGS) constellation aboard the fifth launch of Japan's H2-A rocket in March 2003. The launch was also viewed as a demonstration of the H-2A's reliability, an important factor for Japan's space programme since the H-2A has been designated as the preferred rocket for Japanese government payloads. Indeed, ensuring the reliability of the H2-A launcher was the main priority of Japan's interim space policy, set in 2002 by Japan's top space policy body, the Space Activities Commission (SAC). It was also hoped that the vehicle would be competitive in the commercial launch market.

These expectations were shattered by the failure of the sixth launch of the H2-A rocket on 29 November 2003, which caused the loss of two IGS. This failure is expected to cause significant delays in the Japanese space programme, notably the launching of three additional satellites for the IGS constellation. Other missions have been postponed, including the Engineering

Test Satellite 8 (ETS-8), which has been moved from 2004 to 2005. The Wideband Internetworking Engineering Test satellite and the Selene moon mission, both scheduled for launch in 2005, have been pushed back to 2006 or 2007. To put the programme back on track, JAXA received an extra JPY 7.4 billion (USD 68 million) for 2004 to make improvements on the H2-A rocket in order to return it to flight status.

A review of institutional and regulatory obstacles to the development of the sector

This section reviews some of the major obstacles to the development of the sector which have been identified in recent publications. No attempt is made to attribute the opinions expressed to any particular individual or institution. The opinions are presented for discussion purposes only and cannot be taken to represent in any way the views of the OECD.

Market access restrictions

Since the WTO Agreement on Basic Telecommunications was signed in 1997, a number of countries have considerably reduced cross-border restrictions on market access. More countries now permit: *i)* multiple entities to obtain service licences for their own or third-party use; *ii)* ownership and operation of private Earth station equipment; *iii)* choice in providers of satellite capacity; and *iv)* unrestricted private ownership and operation of transmission/broadcasting facilities. The ABT may also be indirectly influencing the regulatory action of non-signatories. The net result has been a dramatic increase in cross-border investment in satellite communications services and facilities as well as in the satellite services available to the public and the business sector.

For many observers, however, the liberalisation process is still incomplete. It is argued that regulatory barriers remain in place in parts of the Americas, Europe, Asia, Africa and the Caribbean, either because certain countries have not signed the ABT or because of insufficient infrastructure. Moreover, it is pointed out that even in countries that are ABT signatories, opaque national licensing procedures remain a major obstacle to new investment in satellite infrastructure and to the availability of new satellite services. This creates an uncertain environment in which investors and operators cannot be sure that they will be able to obtain a licence in a timely fashion.

Procurement policies

Because public space markets still represent the most important market for the space industry, governments' procurement policy is viewed as having a major bearing on the health of space firms.

However, critics contend that in a number of cases, procurement policy is not as effective as it could be. First, it is argued that governments do not always take advantage of products and services that are readily available from commercial sources. Second, it is noted that governments face political and institutional imperatives that limit their ability to be reliable and predictable customers and partners for industry.

In addition, barriers are believed to result from the lack of interoperability of space-based systems, even among public space systems in the same country. Many valuable and cost-effective uses of existing space-based capabilities cannot be implemented because the various systems cannot communicate and interconnect. Interoperability would allow cost-effective integration of diverse types of information. However, the development and promulgation of standards require centralised co-ordination. Space agencies are therefore encouraged to work with the industry to develop interoperability standards for space systems and to provide direct support to industry to implement these standards.

Export controls and investment restrictions

Because of the dual (civil/military) nature of space technology, governments may want to control the international transfer of such technology on national security grounds. However, this legitimate policy concern may be addressed in ways that interfere with the normal conduct of business. In this regard, existing US legislation regarding export controls has been heavily criticised. This includes the Strom Thurmond National Defense Act of 1998, which is viewed as having created significant barriers to commerce, especially for the satellite industry, by restricting exports of payloads that could be launched on rockets from other countries. The Act transferred the authority over export controls from the Department of Commerce (DoC) to the Department of State (DoS), effective 15 March 1999. Since that time, there have been serious delays in approval or prohibition of exports. Moreover, problems have been reported regarding the ability of US companies to communicate with their foreign affiliates. According to some experts, the US industry may have suffered at least a 16% decline in its share of the GEO satellite market since the transfer of jurisdiction. US technology transfer rules for satellites also apply to sensitive content provided by the United States that may be used by non-US satellite manufacturers. This had led companies such as Alcatel Space to seek to eliminate US content that

might allow American authorities to block exports of their satellite to countries like China by investing in a new component-supplier base. However, this is a costly strategy which other suppliers may not be prepared to follow. For instance, EADS Astrium officials feel that, at least in the near term, the markets that pose problems for the US government are too limited to justify such a move.

Spectrum allocation problems

Over the years, the demand for space radio spectrum has increased relentlessly and will continue to do so in future, despite the introduction of new technologies that offer opportunities for more efficient use of frequencies. First, the number of communications satellites in orbit has continually risen and the satellites have become more powerful. Second, in addition to legitimately planned and financed spacecraft, there has been a proliferation of "paper satellite projects" that presumably intend to market their ITU registration under lease arrangements to new satellite systems that lack "registered locations". Finally, additional demands for spectrum use are likely to emerge as a result of the introduction of new technologies. For instance, high-altitude long-endurance (HALE) platforms are likely to want to use spectrum for communications from "proto-space".

It is argued that, despite the ITU's efforts, frequency allocation and usage as well as interference mitigation are becoming increasingly difficult and burdensome for everyone involved. The ITU backlog in publication of filing is approximately 30 months. This contributes to delays in the ability of satellite operators to bring satellite services to customers. Moreover, evidence suggests that many satellite systems are not using the space segment for the "formally allocated" use specified in the ITU registration. For some observers, this underscores the fact that the ITU allocation process is too slow, extremely limited in terms of flexibility and often inefficient in terms of the types of limitations it imposes.

Several possible improvements have been proposed. First, measures could be taken to improve the allocation process. Second, it has been argued that the ITU should consider rules to optimise the use of orbital arc (*e.g.* a two-degree spacing in appropriate regions of the world). This would, however, require assessment of the impact of current and new technologies and of the ability of operators to co-ordinate the deployment of DTH services with very small terminals.

Some authors have also pointed out that the use of spectrum for uses other than communications should be taken into account. It is suggested that the industry and governments should promote awareness at the ITU and among telecommunications users of spectrum that energy transmission may become a commercial space application and that its spectrum requirements need to be addressed. Supplying the Earth with electric power from space would involve wireless power transmission (WPT) from space to the ground and thus require allocation of radio frequency (RF) spectrum and an assessment of possible interference with telecommunication uses.

Obstacles to the development of new applications

To the extent that new commercial space applications can contribute to public policy objectives and the overall well-being of society, a number of experts argue that governments must encourage their development in the same way as they have encouraged existing services. In particular, governments should explore the potential economic and social benefits to be derived from new space-based capabilities and promote their development through appropriate financial incentives (*e.g.* tax credits, tax-free bonds, loan guarantees, direct loans).

However, policy makers give less attention to the development of commercial space than to civil and national security issues. This is seen as particularly detrimental because commercial investments in space are very costly and technological as well as market risks are enormous, so that the attitude of governments is critical to business decisions to go ahead or not with a particular project. International co-operative efforts and PPPs are particularly vulnerable to policy uncertainties and instability.

Many authors stress that governments should take the lead in long-term R&D, given industry's short-term horizon. They view this as crucial for incubating new and cutting-edge space technologies and ultimately enabling the private sector to apply the resulting technologies on the commercial market. They also point out that new sources of funding for the development of space applications should be explored. Enhanced funding could result for instance from a growing recognition of the crucial role satellites could play in promoting more sustainable development. In this regard, it is argued that financial institutions such the World Bank that are involved in global economic development could bring about more financing and new procurement approaches.

Many experts are also concerned about the greying of the labour force. They wonder how the space industry is to attract new talent from universities and competing industries, in light of the sharp downturn of the last five years or so. Why should engineering graduates consider a career in the space industry, given budget and programme uncertainties and government policies that are subject to frequent changes? This could be one of the greatest challenges for the industry in the years ahead.

Legal and regulatory constraints

Legal constraints are due first of all to the fact that the basic principles of international space law were established in the context of public law. Their application to the business world requires substantial interpretation, a process that is currently under way. Moreover, the dispute settlement provisions in such laws are inadequate for the business world, where the ability to define and enforce the rights and obligations of all parties to commercial contracts and to settle issues of liability is essential. The difficulties raised by the interpretation of the principles of international space law for business purposes also extend to the operations of inter-governmental organisations (IGO) with a mandate relating to space, including the ITU.

The absence of national space legislation or significant differences among existing national space laws can be an obstacle for both public and private space actors in many countries. In the case of public actors, national space laws are important because they represent the best way for governments to discharge their responsibilities under international law. For private actors, the absence of national space laws is a source of uncertainty; it leaves them without guidance regarding how their governments interpret international space law. However, even when national laws are in place, space actors may still face serious legal obstacles, since uncertainties in the interpretation of the principles of international law may lead to differences in national laws, so that the relevant legal provisions differ across jurisdictions.

Regulations are implemented to give effect to existing legislation. In some cases, regulations can facilitate the development of space applications. For instance, regulations can increase the confidence of users of space-related services (*e.g.* regulations on safety, security, privacy) as well as of investors and insurers (*e.g.* clear rules regarding licensing, liability and property rights). Moreover, it is generally agreed that the development of industry standards (notably regarding terminal equipment) can also greatly facilitate the development of new applications. On the other hand, regulation can be an obstacle if it fragments markets, raises costs, unduly delays the deployment of new applications and creates uncertainties (*e.g.* rules regarding spectrum allocation).

Measurement problems

Present understanding of the broader value of space is limited. Space companies, operators, value-adding firms and the research sector measure markets for space in terms of income. This is inadequate for developing and operating space infrastructure and services which often involve a strong public good element. It is necessary to understand the global context for pursuing the broader benefits of space in public services, in commerce and in scientific endeavours.

Concluding remarks

Overall, the space sector is now gradually recovering from the severe recession of the early 2000s following the bursting of the dot.com bubble.

The upstream segment has been hardest hit and is still suffering from chronic oversupply, largely owing to the desire of governments of space-faring countries to maintain assured access to space, at whatever cost. As commercial demand has dried up, the dependence of upstream space firms on government contracts has increased. Strong public demand for space assets, on both the civil and military fronts, is expected to continue, notably in the United States and Europe. An important factor in this regard is the increased focus on domestic security. The demand for space assets is expected also to increase in the rest of the world, as more and more countries wish to take advantage of space applications. However, many markets will be closed to foreign suppliers for strategic reasons, while emerging new space actors from developing countries are likely to represent a growing challenge for Western space firms.

The downstream segment of the sector has weathered the storm much better. Satellite operators have benefited from the good conditions offered during the recession by suppliers of space assets. Moreover, they have been able to consolidate their positions through concentration. Large operators that own satellites in choice orbital positions are in a particularly good bargaining position, which is strengthened by the fact that, for most of their customers, cutting the cost of leasing transponders is not a priority since the space segment only represents a very small component of their total costs, even if it is crucial to their operations.

The main clients of satellite operators, the providers of DBS services, are faring even better than the operators, as communications satellites offer a very effective way to deliver broadcasting services to clients when compared to terrestrial alternatives. However, the situation is less clear for the delivery of broadband services. The emerging broadband satellite market is likely to be a niche market, not only because of the high cost of delivering the service, but also because of the technical difficulties involved in providing an effective return channel. Moreover, the dispersed nature of the potential clientele means that new business models will have to be developed to tap such markets successfully.

Another downstream segment that is doing well is the provision of navigation-based services, which are in high demand and have little effective competition from terrestrial alternatives. On the other hand, the EO market is

a more difficult one, as commercial EO firms face strong competition from terrestrial alternatives and find it hard – if not impossible – to generate sufficient revenue from their activities to cover the high costs that the launching and operation of EO satellites involve.

In the medium term, the sector's recovery will be boosted by government efforts to develop or consolidate their strategic position. In the United States, this is reflected in a significant increase in military space budgets in the coming years, while the development of GMES and Galileo underscores Europe's determination to pursue a more independent security policy in the future.

Over the longer term, the future of the sector remains unclear. Uncertainties relate not only to evolving technology – both in space and on the ground – but also to the overall environment in which the space sector will develop and how this environment will affect the demand for space applications in the coming decades. This question is addressed in the following chapters.

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Exploring the Future of Space Applications

Chapter 2

The construction of synthesis scenarios

The construction of scenarios provides a useful technique for exploring the future. In this process, each scenario represents an alternative vision of the future, i.e. *a point on the map of possible futures. This chapter presents three scenarios for assessing the possible evolution of the space sector over the next three decades. They take into account three major drivers of change expected to have a major impact on the space sector in the future: geopolitical developments, socio-economic developments, energy and the environment.*

Introduction

The early phases of the Space Project have focused on exploring the future evolution of the space sector with a view to identifying space applications that may be promising in the coming decades, *i.e.* applications that are likely to generate significant net social value in either the public or the private sector. On the demand side, this required considering how the evolution of world events, influenced by certain drivers of change, may create an environment that is more or less favourable to future space activities and how this may be reflected in the demand for specific space applications. On the supply side, this involved assessing whether the applications are likely to be technologically feasible at a reasonable cost.

Because of the long timeframe adopted here, a scenario-based approach was adopted for an analysis of the demand side. Indeed, when exploring inherently unpredictable futures – as is the case for the future of the space sector – the building of a range of scenarios offers a superior alternative for decision analysis, contingency planning or mere exploration of the future, since uncertainty is an essential feature of scenarios.

The overall approach used in this report involves: *i)* constructing appropriate scenarios for providing alternative visions of the future evolution of the world; *ii)* sketching out the consequences of each scenario from political, economic, social, energy, environmental and technology perspectives and drawing the implications for the future evolution of the main components of the space sector; and *iii)* assessing the implications for future demand for specific applications. The final step is to assess the technological feasibility of applications identified as "potentially promising" from a demand perspective. This chapter focuses essentially on the construction of the scenarios that underlie the demand analysis. Chapter 3 addresses point *ii)* and Chapter 4 covers both point *iii)* and the technical feasibility assessment.

The following section provides a brief outline of the methodology used to construct the scenarios. The methodology is explained in more detail in Annex 2.A.1, which gives a general rationale for using scenario analysis, outlines the specific approach used and explains how it is applied to the assessment of the future evolution of the space sector.

Scenario methodology

The methodology is based on a "blueprint" widely used by futurists which involves the following steps:

1. Define the question to be answered.
2. Identify the drivers of change with a bearing on the question at hand.
3. Analyse the trends and factors likely to affect each of the drivers of change with a view to assessing the "main uncertainties" that apply to their future state and define the "scenario space".
4. Select in the scenario space the scenarios that will receive particular attention.
5. Flesh out the scenarios and draw their implications for the question at hand.

In applying the blueprint to the future evolution of the space sector, three main drivers of change were identified as particularly pertinent: geopolitical developments, socio-economic developments, and energy and the environment, not only because of the key role they will play in shaping the world, but also because of their close links with the space sector.

A fourth driver of change, technology, was also considered. It was decided not to include it explicitly in the analysis because its impact is likely to be mainly on the supply side. Moreover, technology is implicitly taken into account in the three main drivers and was actually explicitly used in defining some of the driver scenarios.

Because the number of drivers of change is relatively large and because each is very broadly defined, the blueprint could not be applied directly, because it would have led to the definition of a multi-dimensional scenario space. Instead, the analysis was carried out in two stages: in the first, outside specialists in the areas of each of the main drivers were asked to develop "driver scenarios", *i.e.* scenarios that take "their" driver as their main theme, and to draw the implications for the space sector and for space applications; in the second, the three sets of scenarios developed in this way were integrated into "synthesis scenarios".

The following discussion first spells out the core assumptions used by the experts and the Project Team. These assumptions constitute the general framework for the analysis. Then, each of the stylised versions of the scenarios constructed by the experts is reviewed. Finally, the construction of the synthesis scenarios is described.

Core assumptions

The main purpose of the core assumptions is to provide an overall framework for analysis. While they restrict somewhat the range of the

scenarios, they are a way to ensure consistency in the synthesis process. The core assumptions are:

Political: No major war occurs over the period, although regional conflicts, civil wars and terrorism are not ruled out.

Economic: There is no single traumatic economic crisis of the magnitude of the 1929 crisis, although some countries or groups of countries may face severe economic difficulties.

Social: Although social unrest may play a role, it never results in a complete social breakdown. Pandemics are not ruled out but they affect particular countries or regions and/or remain within manageable proportions. Population increases are in line with the UN's medium long-range projection.

Energy: Energy supplies remain sufficient to meet overall demand, although competition for resources may intensify.

Environment: The environment continues to deteriorate. However, there is no major disaster of a global scale resulting in a significant alteration of living conditions.

Technology: Technological progress continues. There is no major technological catastrophe that might result in a technological backlash.

It would, of course, be interesting to explore the impact of a relaxation of some these assumptions. One might consider what would happen, for instance, if a major catastrophe resulted in a technological backlash or in a significant alteration of living conditions on Earth.

The geopolitical scenario: a stylised version

Geopolitical trends and factors

On the political front, a gradual decline in the power wielded by nation-states and in the role they are expected to play is an important long-term future trend. This could have major implications for the future organisation of society. First, secessionist movements may be in a stronger position to wrest power from central governments, and more sub-national entities might gain independence. Second, the number of failed states might rise. In contrast, international organisations, non-state actors, including multinational corporations, non-governmental organisations (NGOs) and also organised crime and terrorist groups, are likely to become more powerful.

However, nation-states are not expected to disappear. Indeed, they should remain the main focal point of international relations over the next three decades, although they will face a more complex political environment as non-state actors become increasingly active. In addition, the pecking order of nations is expected to change. Western nations are expected to lose ground overall while new players may move ahead and become regional powers. The

United States is expected to remain in the lead, but its lead should gradually diminish and may even be challenged by China towards the end of the period. Co-operation among "lesser powers" with a common interest in the emergence of a less hegemonic world order may intensify.

On the military front, future conflicts are expected mainly to be intra-state and increasingly to involve non-state actors, such as terrorist groups or organised crime. The proliferation of weapons of mass effect (WME) will heighten concerns about domestic security in most countries. In response, the United States (which will remain the dominant military power over the period) is expected to adopt, at least initially, a dual strategy of homeland security (including the construction of a national missile shield) and of pre-emptive use of military force abroad. The Europeans, too, are expected to strengthen their domestic security and consolidate their collective defence. China, India and Russia may enhance their military capability as well and are likely to seek to deter intervention by the United States through their WME.

Main uncertainties

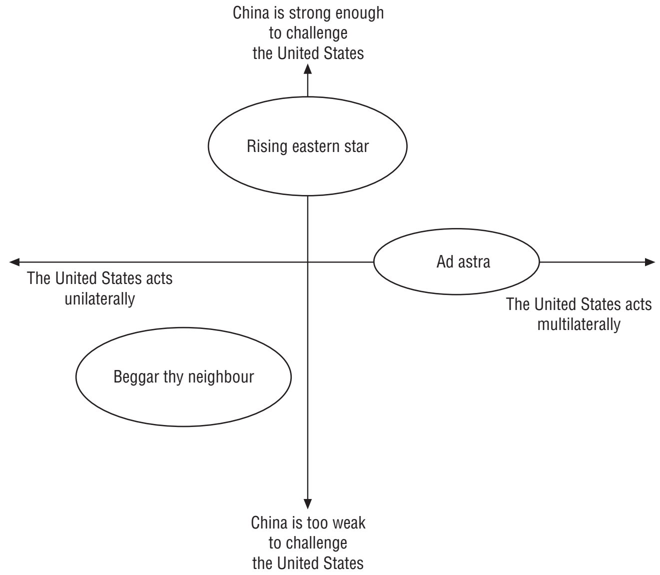
The first main uncertainty is whether the world will continue to be unipolar over the period, or whether another nation or a coalition of nations will be able to challenge the United States. In the first instance, the future geopolitical environment will be largely determined by action taken by the United States; in the second case, a new form of international rivalry may emerge, reminiscent in some ways of the cold war, but in a very different context.

If the world remains unipolar throughout the period, attitudes taken by the United States towards the rest of the world will largely determine whether international co-operation increases or decreases. In effect, the world will face two opposing trends. On the one hand, the nation-state's loss of sovereignty and the growing importance of international law would lead to the emergence of a new world order characterised by peace and increased international co-operation in a more open world. On the other hand, the weakening of the nation-state, the growing power of non-state actors, the rise of asymmetric threats and the emergence of new state powers could lead to disorder. As the major world power, the United States would be in a position to influence which of the trends prevails.

Definition of the scenario space

Whether or not the United States acts unilaterally in the future and whether or not China becomes strong enough over the next 30 years to be able to challenge the United States are used as drivers to define the scenario space (Figure 2.1). The definition of the scenario space is of course somewhat

Figure 2.1. **Geopolitical scenarios**



Source: OECD.

arbitrary, and other drivers could have been considered. For instance, the possibility of Europe becoming a leading actor in many policy areas could be envisaged, if the move towards a European federal state structure were to accelerate.

If the unipolar world is maintained, international relations will largely be shaped by the action of the only superpower. If the United States chooses to act unilaterally, the result could be a world dominated by *realpolitik*, *i.e.* a world where action is largely driven by nationalistic considerations and results in confrontation rather than co-operation. In an increasingly interdependent world, confrontation would have significant adverse consequences. However, if the United States chooses instead to act as a "benign hegemon", it could use its dominant position to strengthen international institutions and foster international co-operation. For the United States, the choice may involve trade-offs between short-term and longer-term objectives, which will have to be set against the backdrop of increasing challenges to nation-states.

If instead the world evolves towards a bipolar configuration, with China as the challenger, the change in the balance of power might significantly alter international relations. The performance of the Chinese economy over the last 20-30 years makes such a development plausible, although a number of experts are sceptical. They point to the major difficulties China will have to overcome rapidly and to the fact that it cannot sustain its current rate of growth for very long. Should this bipolar world develop, however, the geopolitical consequences could be substantial, given China's feeling of earlier humiliation by the West and its growing concerns about food and energy self-sufficiency. A new form of cold war might arise, although the composition of the two blocs and the socio-economic context would probably be very different from the situation that prevailed in the post-World War II period.

The geopolitical scenarios

In this scenario space, the authors identified three scenarios:

- ***Beggar thy neighbour:*** A deterioration in international relations results in a fragmented world economy and the rise of protectionism. Economic growth slows, causing increased social and political tensions in OECD countries and in the rest of the world. The environment deteriorates and access to energy resources is a source of tension among major consuming countries. Security concerns rise, triggering substantial increases in expenditures on military hardware worldwide.
- ***Ad astra:*** A strengthening of international relations creates a more favourable climate for economic growth. In a spirit of international co-operation, more attention is given to solving the problems that plague developing countries. Income inequalities, poverty and malnutrition are significantly reduced. Effective measures to reduce greenhouse gas (GHG) emissions are put in place. Energy markets work smoothly and military budgets are reduced.
- ***Rising eastern star:*** While economic growth in the West remains sluggish, the Chinese economy continues to grow at a healthy rate. Faced with growing needs for food and energy, China flexes its muscles on the international scene to acquire what it considers "its fair share". Growing tensions with the West result, as the world gradually moves to a bipolar configuration. The West responds by closing its markets to Chinese goods. A new form of cold war emerges in which each side devotes considerable resources to military hardware and to extending its "soft power" as widely as possible.

Like the choice of drivers, the choice of scenarios within a given scenario space is also arbitrary. For instance, instead of the "beggar thy neighbour" scenario, in which every nation acts on its own, a scenario in which US unilateralism causes other nations to co-operate to achieve a more level playing field could be envisaged.

Table 2.1 outlines the global consequences of each of the scenarios.

Table 2.1. **The stylised geopolitical scenarios**

	1) Beggar thy neighbour	2) Ad astra	3) Rising eastern star
Economic	Economic growth uneven owing to regionalisation and protectionism. Increasing economic disparities within and among countries.	Strong economic growth owing to further liberalisation of trade. Decreasing but persistent economic disparities within and among countries. China and India emerging as new regional economic powers.	Continued high economic growth in China, lower economic growth in the United States. Protectionism and regionalism either co-existent with or a result of Chinese progress.
Social	Increasing social pressures owing to greater economic disparities. Developing countries find it hard to deal with the burden of population increase, urban migration and demographic change.	More attention paid at international and national level to alleviate demographic burden of developing countries. Economic growth "matches" population growth.	Same as in scenario 1).
Political	International treaties and organisations suffer under increasing American unilateralism and European, Russian and Chinese retaliation. Europe reinforces its common foreign policy. Regional arrangements appear in Asia.	Multilateralism prevails. Strengthened international organisations and agreements. European co-operation strengthened. Asia remains multilateral.	International agreements under strain, Potential US-European alliance against China. Japan seeks US support. India feels threatened by a Chinese hegemony in Asia.
Technological	Medium level of technological innovation. Low diffusion towards developing countries. Focus on military technology, but with possible spillover effects to civil use.	High level of technological innovation. High diffusion towards developing countries. Commercially and publicly driven research.	High level of state investment in military defence technology. Very low diffusion.
Environmental	Continued aggravation of environmental problems. Water and food scarcity. Extreme weather and natural catastrophes owing to global warming and climate change.	Joint international efforts and improved technology to tackle environmental problems. An increase, then a decrease in CO_2 emissions, owing to economic growth in developing countries. No water or food scarcity.	Same as in scenario 1). Chinese wealth and focus on military and economic progress aggravate environmental problems in China.
Energy	Despite sufficient energy supply, increasing fossil fuel prices and supply cuts owing to tense geopolitical environment and dependency on suppliers in Central Asia and the Middle East.	Supply of fossil fuels secure. Development of alternative energy sources.	Energy competition: China tries to influence Central Asia and to secure its interests in the Middle East to ensure a stable energy supply.

Source: OECD.

The socio-economic scenario analysis: a stylised version

Socio-economic trends and factors

On the demographic front, world population growth is expected to slow, with all of the increase occurring in the developing world. Population ageing will become a global phenomenon, although it will be more pronounced in the West and in some non-Western countries, notably China and Russia. In developing countries, more of the population will move from rural to urban areas, creating the need for massive investment in infrastructure. More people will also migrate from the developing world to the West, creating a continuing source of tensions in Western societies as well as new opportunities. Culture should become increasingly globalised, although resistance to change and retrenchment may be strong in the more traditional societies, leading to bouts of fundamentalism. In contrast, Western societies are likely to become more secular, pragmatic and individualistic, as well as more difficult to govern, as respect for established authority declines.

From an economic perspective, the world may become a better place to live in for more people in the next 30 years. Not only is population growth slowing, but the economy may improve if the globalisation process continues, as major new technologies come on stream and spur growth. However, economic risks will tend to increase: poor governance both at national and international levels is likely to be more severely penalised by market forces, and economic shocks could have devastating ripple effects in an increasingly interdependent world. Moreover, income inequalities are expected to grow both within and between countries, while unemployment may be a major source of unrest in countries in transition. Poverty should decline overall but is likely to be increasingly concentrated in certain regions of the world, notably Africa and South Asia.

Main uncertainties

The world faces two opposing trends: on the one hand, globalisation and the gradual liberalisation of markets are necessary to ensure that growth is sufficient to reduce poverty, to raise income levels in the developing world and to provide the resources needed to maintain the welfare system in OECD countries. On the other hand, if the gains from these market trends are very unequally shared, there may be mounting tensions worldwide and rejection by large segments of the population. The key question for the future is thus whether the liberalisation process will continue, *i.e.* whether the measures to be taken in the coming years to strengthen governance, both at national and international levels, and to reduce poverty and income inequalities will be sufficient to avoid a widespread rejection of the globalisation process.

Definition of the scenario space

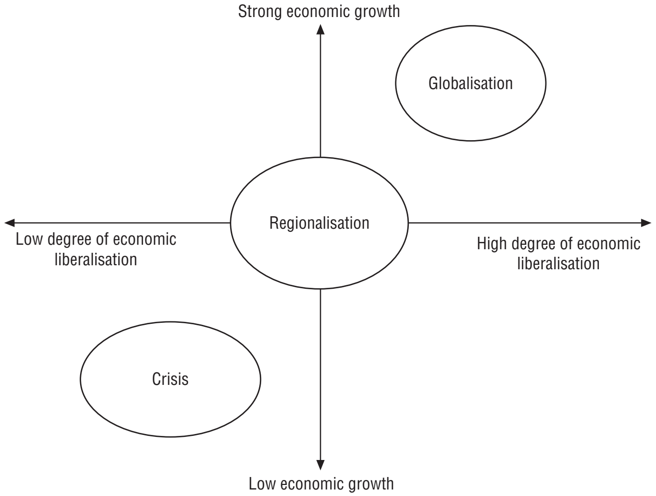
The degree of liberalisation is used as the main scenario driver. Since World War II, the world economy has experienced an unprecedented period of expansion (largely owing to a gradual liberalisation with respect to the movement of goods, services, investment and individuals). The question is whether this process will continue, despite the potential gains to be achieved worldwide. Several factors are at play: *i)* the number of members of the World Trade Organization (WTO) has increased significantly, thereby reducing the probability of consensus on further liberalisation; *ii)* "low-hanging fruits" have already been picked, *i.e.* the issues to be addressed are increasingly difficult politically (*e.g.* agriculture, intellectual property rights, investment); *iii)* some of the major movers behind freer trade may be less committed than in the past (*e.g.* they take unilateral action when loss of jobs is at stake in politically sensitive areas or industries or enter into bilateral trade agreements for strategic reasons, to the detriment of the multilateral regime); *iv)* segments of the population that feel left out and governments that resent the *diktat* of market forces or fear systemic risks in an increasingly interdependent world may oppose further liberalisation. Whether the liberalisation movement continues will largely depend on whether such obstacles can be overcome. Otherwise, the world might revert to a situation akin to the one that prevailed in the post-1929 period, *i.e.* with an economic slowdown resulting in significant social and political unrest in a large number of countries.

The socio-economic scenarios

In this scenario space, the authors identified three scenarios (Figure 2.2):

- ***Globalisation:*** Further liberalisation of the world economy in a spirit of international co-operation results in economic gains that largely benefit developing countries. Poverty and malnutrition are gradually reduced. Joint efforts are taken to address environmental problems and energy markets work smoothly.
- ***Regionalisation:*** As the WTO process grinds to a halt, more and more countries decide to enter into bilateral agreements with other nations or to create regional arrangements. Substantial trade diversion results. A complex web of trade agreements emerges worldwide and contributes to a gradual erosion of WTO discipline. Economic growth slows and income inequalities increase, fostering social and political tensions, while little progress is made on the environmental front.
- ***Crisis:*** World economic growth is stalled by two developments. The global multilateral system fails and countries turn to regional or bilateral arrangements. Furthermore, US productivity declines; the resulting slow growth in the OECD region extends to the rest of the world. Both developing

Figure 2.2. **Socio-economic scenarios**



Source: OECD.

and developed countries have to deal with increasing social tension, as reduced public budgets are inadequate for coping with existing problems and with new ones as they emerge. The environment is low on the priority list.

Table 2.2 outlines the global consequences of each of the scenarios.

The energy and environment scenario analysis: a stylised version

Energy and the environment: main trends and factors

The environmental outlook is bleak. As GHG emissions may more than double over the next 30 years, a rise in the mean temperature appears inevitable, causing a noticeable rise in sea levels, more unstable weather conditions and a geographical shift in endemic and infectious diseases. Implementing appropriate GHG abatement policies at international level will prove difficult because of economies' high dependence on fossil fuels and because of the externalities involved (*i.e.* polluters only pay a fraction of the costs they impose on society at large). Higher levels of pollution at the local level are also expected in large parts of the developing world, together with further deforestation, soil erosion and reduced biodiversity. On the other hand, OECD countries as well as a number of middle-income countries should give greater attention to environmental issues.

Table 2.2. **The stylised socio-economic scenarios**

	1) Globalisation	2) Regionalisation	3) Crisis
Economic	High economic growth, owing to further liberalisation of trade. Decreasing but persistent economic disparities within and among countries. China and India emerge as new regional economic powers.	Economic growth uneven owing to regionalisation and protectionism. Increasing economic disparities within and among countries.	Zero economic growth in most parts of the world. Danger of general breakdown. Emerging economies particularly strongly affected by the crisis.
Social	More attention paid at international and national level to alleviate demographic burden of developing countries. Economic growth "matches" population growth.	Increasing social pressures owing to increasing economic disparities. Developing countries find it hard to deal with the burden of population increase, urban migration and demographic change.	Both developing and developed countries have less money to deal with rising social tensions, whether ageing populations or unemployment. Reduced social spending and welfare-state reform in developed countries.
Political	Multilateralism prevails. Strengthened international organisations and agreements. European co-operation strengthened. Asia remains multilateral.	International treaties and organisations suffer under increasing American unilateralism and European, Russian and Chinese retaliation. Europe reinforces its common foreign policy. Regional arrangements appear in Asia.	Countries focus on domestic problems owing to difficult economic climate. International co-operation, if any, along regional lines. Some international efforts to fight against increasing transborder crime and migration.
Technological	High level of technological innovation. High diffusion towards developing countries. Commercially and publicly driven research.	Medium level of technological innovation. Low diffusion towards developing countries. Focus on military technology, but with possible spillovers to civil use.	Low level of technological innovation. Focus on cost-saving technologies. Research driven by public-private partnerships.
Environmental	Joint international efforts and improved technology to tackle environmental problems. An increase, then a decrease in CO_2 emissions, owing to economic growth in developing countries. No water or food scarcity.	Continued aggravation of environmental problems. Water and food scarcity. Extreme weather and natural catastrophes owing to global warming and climate change.	Pollution and CO_2 emissions stabilise owing to reduced consumption and lack of economic growth in Asia, but little technological innovation to reduce dependency on conventional energy sources. Low environmental awareness.
Energy	Supply of fossil fuels secure. Development of alternative energy sources.	Despite sufficient energy supply, increasing fossil fuel prices and supply cuts owing to tense geopolitical environment and dependency on suppliers in Central Asia and the Middle East.	A continuously tense political climate in the Middle East opens the search for local or alternative energy sources. Fossil fuel reserves last longer than projected owing to low demand.

Source: OECD.

On the energy front, fossil fuels are expected to continue to dominate primary energy consumption. Oil will remain the leading fuel. While oil reserves should remain sufficient to meet demand, major investments will be required for exploration, extraction and transport. Moreover, the price of oil may become more volatile, as conventional energy reserves decrease and are more concentrated in the Persian Gulf area. Gas is likely to continue to be the fossil fuel of choice for electricity generation, because of its relatively low carbon content; hence, demand for gas is expected to rise rapidly. Demand for carbon-intensive coal should increase at a lower rate, while nuclear power will remain contentious, despite its clear advantage from the perspective of GHG emission. Greater efforts will be made to promote the use of renewables, but their overall share of energy consumed will remain very low, as it will prove extremely difficult to steer the energy system away from fossil fuels.

Main uncertainties

The two main uncertainties are the rate of technological change and the level of people's concern about the environment. On the one hand, a rapid rate of technological change should spur economic growth and result in increased use of energy and a rise in GHG emissions. On the other hand, technology may help to improve the energy efficiency of production and offer new approaches for reducing pollution and/or lowering the impact of energy production and energy use on the environment. If the population is very concerned about the environment, people are likely to be more willing to accept GHG abatement measures that may require painful adjustments to their way of life and to support increased investment in energy technology research. Other things being equal, it seems plausible that the level of concern will increase more or less in parallel with an increase in environmental problems. However, if those who are better placed to take abatement measures decide instead to adapt to the change in climate (*e.g.* build higher dams against floods, adopt more heat-resistant crops, air-condition their homes and offices), the costs of climate change will fall largely on those who are less able to adapt, mainly in the developing world.

Definition of the scenario space

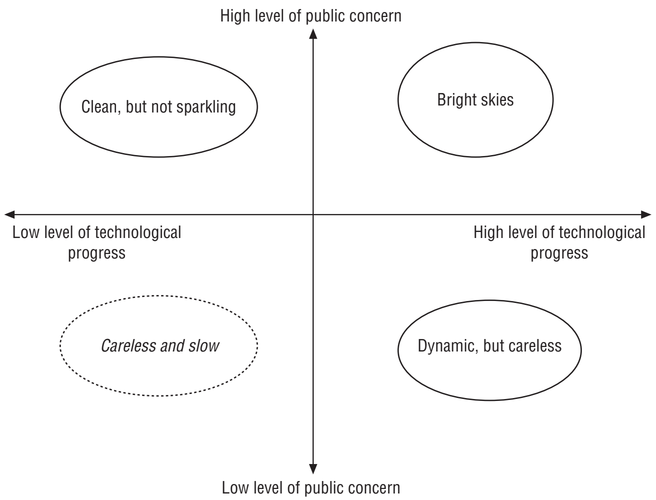
The rate of technological innovation and the level of public concern about the environment are used as drivers to define the scenario space. Technological change is likely to have a major and complex impact on the energy situation and the state of the environment. This can be illustrated by the use of the so-called Kaya identity (Kaya, 1990) as reported by the International Panel on Climate change (IPCC) (2000, Chapter 3):

$$CO_2 \text{ emissions} = \text{population} \times (\text{GDP/population}) \times (\text{energy/GDP}) \times (CO_2/\text{energy})$$

Technological development contributes to an increase in carbon dioxide (CO_2) emissions as a result of its impact on per capita gross domestic product (GDP) (second term in the Kaya identity). However, it can contribute to reduced emissions if it lowers the amount of energy per unit of GDP (third term in the identity) and if it allows switching to less polluting forms of energy, *i.e.* those that produce less CO_2 per unit of energy produced (the fourth term in the identity). It has been estimated (Watson *et al.*, 1996) that energy-related CO_2 emissions since the middle of the 19th century have increased by about 1.7% a year, with a 3% growth in gross world product (the sum of 1% growth in population and a 2% growth in per capita income) compensated partially by a 1% a year decline in energy intensity (energy/GDP) and a decline in the carbon intensity of primary energy (CO_2/energy) of 0.3% a year (Watson *et al.*, 1996). Changes in the composition of output as a result of rising living standards (*e.g.* the increasing importance of services in consumption) also play a key role. Although these aggregate historical results provide an order of magnitude, they cannot be used for projection purposes because results are very different at the regional level and vary considerably with regard to the level of per capita energy consumption. Moreover, the composition of primary energy may change for the worse in future if and when oil and gas are depleted and if demand for coal increases as a result.

The level of public concern about the environment is expected to play a key role for the future state of the environment for two main reasons. First, it may directly affect individual behaviour, *e.g.* concerned citizens are more likely to adopt voluntarily consumption patterns that are environmentally friendly. Second, public concern can translate into political support for the adoption of green policies by governments. Without such support, democratic countries are unlikely to adopt such policies, since they impose immediate and tangible costs on society at large, while the benefits may be perceived by many as hypothetical, too distant or accruing to others. Empirical investigation suggests an inverted U-shaped relationship between pollution and economic development, known as the environmental Kuznets curve, which reflects the changes in public attitudes towards the environment as income rises. It is suggested that in the first phase of industrial development pollution increases rapidly as people are more interested in jobs and income than in clean air and water. Moreover, communities are too poor to pay for pollution abatement, and environmental regulation is weak. However, as income rises, people start to value the environment more highly and regulatory institutions become more effective. Empirical findings suggest that air and water pollution reach their peak in middle-income countries (with per capita income ranging from USD 5 000-8 000) (IPCC, 2000; Dasgupta *et al.*, 2002). This phenomenon seems to be well established for traditional pollutants (*e.g.* particulates and sulphur), but views differ with regard to GHG

Figure 2.3. **Energy and environment scenarios**



Source: OECD.

emissions. Moreover, the flatness of the Kuznets curve may vary considerably from country to country, depending on differences in values and institutions.

The energy and environment scenarios

In this scenario space, the authors identified three scenarios (Figure 2.3):

- ***Dynamic, but careless.*** Current trends continue, with low public awareness of environmental problems and high economic growth causing increased energy consumption and pollution. The increase is primarily in Asia. The search for alternative and local energy sources becomes more important.
- ***Bright skies.*** The scenario combines economic progress with rapid technological progress and increased public concern for the environment. The result is a dynamic and positively changing world, where significant progress towards more sustainable forms of development is possible.
- ***Clean, but not sparkling.*** The third scenario is the most distinct, and perhaps the most marginal, of the nine scenarios. It envisages a complete change of mentality in favour of the environment worldwide. Economic growth is slower and technological progress moderate.

Table 2.3 outlines the global consequences of each of the scenarios.

Table 2.3. **The stylised energy and environment scenarios**

	1) Dynamic, but careless	2) Bright skies	3) Clean, but not sparkling
Economic	High economic growth in developed and developing countries. Disparities within and among countries persist but are decreasing.	High economic growth, same as in scenario 1).	Lower economic growth than in 1) and 2). Disparities decrease.
Social	Social tensions owing to economic disparities. Developing countries only partly capable of coping with population increase, migration and demographic change.	Joint international efforts and national concern ease effects of demographic changes in developing countries.	Demographic pressures. Developing countries need to develop social security schemes. Rising unemployment.
Political	Well-developed international organisations, but their influence is issue-dependent. Strong position of "business" civil society and multinational companies. Strong focus on security of energy supply and interventionist action towards oil producing countries.	Strengthening of international organisations and the Kyoto Protocol. Strengthening role of "green" NGOs and civil society. Government attention to the importance of environment and sustainable development. Public/private partnerships.	International agreements and organisations supported by civil society. Strong international solidarity and help. Strong environmental commitment. Strengthening of "green" civil society. Mentality change.
Technological	Focus on efficiency gains and search for alternative energy sources. Medium diffusion.	Strong supply-side measures and R&D investment. Sequestration technology improvements. High diffusion.	Medium technological progress – no breakthroughs but existing technology improved. High/medium diffusion.
Environmental	Aggravation of environmental problems, especially in the developing world. Water stress. Climate change and global warming. Deforestation.	Environmental problems worsening at first, owing to economic growth in developing countries, but negative effects reduced by high public concern, government intervention and new technology. Water problem solved?	Environmental problems relieved by changed lifestyles and improved technology.
Energy	Strong dependency on fossil fuels.	Energy demand increases owing to economic growth. Decreased dependency on fossil fuels. Nuclear energy loses ground.	Oil replaced by natural gas. Move towards replacing fossil fuels altogether by emission-free renewables.

Source: OECD.

A fourth scenario, "careless and slow", not considered by the outside experts, might also be envisaged. It is characterised by slow technical progress and a low level of public concern about the environment. Anti-technology sentiment is on the rise, while the public is more concerned with security and socio-economic issues than with the state of the environment. This scenario, which is presented by a dotted-line ellipse in the third quadrant of Figure 2.3, is used in one of the synthesis scenarios described below.

An overview of the synthesis scenarios

The next step in the analysis is to integrate the scenarios based on the drivers of change into three synthesis scenarios that are both plausible and internally consistent. For instance, it would be highly unlikely that rapid economic growth would occur when geopolitical tensions are high. Also, concern about the environment is likely to be lower when economic growth is slow and international relations poor. On the basis of these considerations, three synthesis scenarios combine elements of the scenarios described above.

Synthesis scenario 1 (*smooth sailing*): This is an optimistic scenario reflecting a virtuous circle involving the three main drivers. Specifically, it combines the geopolitical developments of the *ad astra* scenario with the socio-economic future outlined in the *globalisation* scenario and the energy and environment developments reflected in the *bright skies* scenario. Under *smooth sailing*, the world is at peace, multilateralism and international co-operation prevail, globalisation brings prosperity to the world, notably the developing world. Poverty is significantly reduced, energy supplies are adequate to meet demand and effective measures to clean up the environment are taken collectively.

Synthesis scenario 2 (*back to the future*): This is a "middle of the road" scenario that combines the *rising eastern star* geopolitical scenario with the *regionalisation* socio-economic scenario and the *dynamic, but careless* energy and environment scenario. It basically describes a return to a bipolar world where international relations are dominated by the uneasy interaction between the two blocs: the United States and Europe, on the one hand, and a coalition of China and Russia, on the other. Despite the political difficulties, economic growth remains reasonably good in OECD countries under an economic regionalisation scenario involving closer co-operation between the United States and Europe. However tensions are on the rise on several fronts, notably over the environment and energy security.

Synthesis scenario 3 (*stormy weather*): This relatively pessimistic scenario reflects a vicious circle between the *beggar thy neighbour* geopolitical scenario and the *crisis* socio-economic scenario. *Stormy weather* describes a world where a breakdown in multilateralism, caused by strong divergence of views among

key actors, precipitates an economic crisis that further exacerbates international relations. Economic growth is likely to be slow and concern about the environment low (the *careless and slow* energy and environment scenario).

The three scenarios are presented in more detail in Chapter 3. They offer three alternative visions of how the world might evolve in the future. However, none is "more likely" than the others: all three should be considered both plausible and unlikely. They represent only three points in the set of possible futures. They illustrate the fact that the future will not be a mere extension of the present. They also offer a useful basis for reflecting on how the space sector might evolve in the coming years.

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ANNEX 2.A.1

Scenario methodology

In the early phases of the Space Project, the Project Team was asked to analyse the sector's longer-term prospects and to assess the potential future development of existing space market segments and the likely emergence of new markets over the next 30 years or so. The study was to take a largely "top-down" approach and focus on the drivers of change expected to have a major bearing on future conditions of supply and demand.

This annex outlines the scenario-based methodology used as a basis for Chapters 2 to 4. First, it gives a general rationale for using scenarios analysis. It then outlines the specific approach used to construct the scenarios, and finally it explains how the method is applied to evaluate the future evolution of the space sector.

Why create scenarios?

To explore the future, analysts can choose among various techniques, depending on the nature of the exercise involved. Forecasting is perhaps the most prevalent technique. It employs forecasting models that provide a simplified description of reality and of the relations that are believed to exist between independent or exogenous variables (the values of which are determined outside the model) and dependent or endogenous variables (the values of which are generated by the model).

Forecasting models are useful for short-term projections, but they are of little value for exploring the long-term future. This is because such models depend on "structural inertia", *i.e.* they implicitly assume that the underlying structure of the model (more specifically the relation between the dependent and independent variables) does not vary over the forecasting period. While this assumption may be reasonable for the short term, it is unlikely to hold in the longer term. Attempts can be made to deal with this problem by developing several forecasts based on alternative values of some of the

structural parameters. However, in this approach, uncertainty is treated as an excursion around a "preferred" or "most likely" path or destination.

For futures that are inherently unpredictable, a range of scenarios offers a superior alternative for decision making, contingency planning or mere exploration, since uncertainty is an essential feature of scenario analysis. Individual scenarios provide a rich characterisation of alternative futures. Their goal is to describe a coherent future world by means of a credible narrative. Taken together, several scenarios are likely to contain the future state, although no individual scenario would describe it.

In this report, the scenario approach is clearly preferable, since the drivers are broadly defined and involve complex interactions with a wide range of variables over a long period of time.

A general approach to the construction of scenarios

The "blueprint" adopted here for constructing scenarios is largely based on an approach widely used by futurists, notably by Rand Corporation experts (for a recent example, see Baer *et al.*, 2002). It can be described as a form of "qualitative modelling" and involves five main steps:

1. Define the question to be answered (by analogy with traditional modelling, this is equivalent to defining the dependent variable).
2. Identify the drivers of change with a bearing on the question at hand (this corresponds in quantitative modelling to the identification of independent variables). As in quantitative analysis, it is important to simplify reality by concentrating on a small set of drivers, as the analysis otherwise quickly becomes unmanageable.
3. Analyse the trends and factors likely to affect each of the drivers of change with a view to assessing the "main uncertainties" that apply to their future state (in quantitative modelling this is equivalent to projecting the range of values that independent variables may take in the future). The various future states of the drivers define the "scenario space".
4. Select the scenarios that will be given particular attention in the scenario space.
5. Flesh out the scenarios and draw the implications for the question at hand.

The following is a brief description of how the blueprint can be used in practice. Table 2.A.1.1 covers the first three steps. In step 1, it is assumed that the question to be addressed is the future prospects of the world economy. In step 2, it is decided, on the basis of past experience, that international trade and technical change are the main determinants of economic growth in the longer run. These two variables are therefore chosen as the main drivers for the analysis. Step 3 consists in identifying what might be major uncertainties

Table 2.A.1.1. **First three steps in the scenario-based analysis of long-term prospects for the world economy**

	Specific example
Question to be answered	What are the future prospects for the world economy?
Key drivers	International trade, technical change
Main uncertainties	Level of trade liberalisation, rate of development and diffusion of new technologies

Source: OECD.

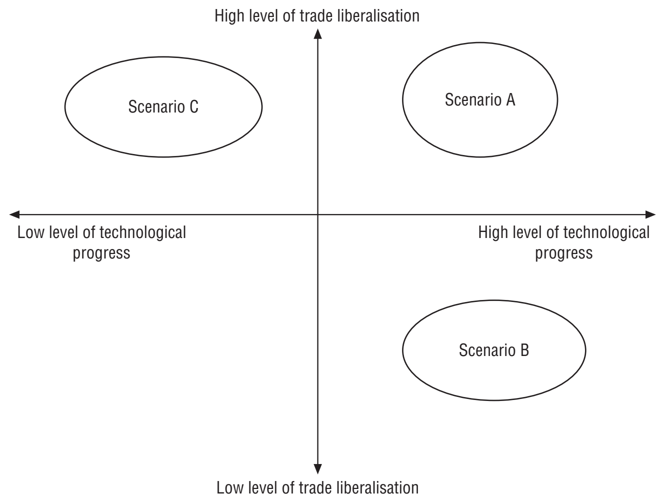
with respect to these two drivers. For international trade, the main uncertainty is the degree of trade liberalisation, *i.e.* the extent to which trading nations will agree in future to maintain an open trading environment. For technical change, the main uncertainty relates to the level of R&D that will take place in future and to the speed of diffusion of new technologies throughout the world.

The two uncertainties can then be used to define a two-dimensional scenario space, as illustrated in Figure 2.A.1.1. The rate of technical change is represented on the horizontal axis, ranging from "low" on the left to "high" on the right. Similarly, the level of trade liberalisation is represented on the vertical axis, ranging from "high" in the upper part of the figure to "low" in the lower part. In practice, of course, the concepts of "high" and "low" need to be carefully qualified.

Once the scenario space has been defined, the scenarios can be selected. This is illustrated here by scenarios A, B and C which appear in the first, second and fourth quadrants and represent different possible combinations of the key drivers.

The final step in the analysis consists in drawing the implications of the scenarios for the question at hand, *i.e.* the long-term prospects of the world economy. In this schematic example, scenario A represents the most favourable outcome: both trade liberalisation and rapid technical change contribute fully to rapid economic growth. Prospects for world growth are less good in scenarios B and C but for different reasons. In scenario B there is rapid technological change, but the benefits cannot be fully exploited because international trade is impeded by trade barriers. In scenario C, the situation is the opposite: trade liberalisation is important but the rate of technological change is sluggish. When each of the scenarios is fully fleshed out, it becomes possible to draw some implications regarding the measures that would be needed to create the conditions for realising the preferred scenario.

Figure 2.A.1.1. **World economy scenarios**



Source: OECD.

Application of the methodology to space

This approach is applied to the exploration of the future of the space sector and of the development of space applications.

Three drivers of change were identified as particularly pertinent in this regard, namely geopolitical developments, socio-economic developments and energy and the environment, not only because of the key role they will play in shaping the world, but also because of their close links with the space sector.

First, the sector is closely linked to geopolitical developments since space represents the ultimate "high ground". Space assets can play a key role in intelligence, communications, command and control (IC3), and control over space weapons can put a space power in a dominant position.

Space also has a firm link to socio-economic developments. Only countries with a strong economy can contemplate becoming major space-faring nations. Moreover, space assets can make a substantial contribution to the economy and society at large. In particular, they provide a unique way to collect and deliver information services (communications, Earth observation, navigation) over vast territories with minimum terrestrial infrastructure.

There is also a strong relation between energy and the environment and space. Space assets can be used to monitor the state of the environment, to anticipate weather changes and to provide assistance when ecological disasters occur. They can also be used to manage natural resources more effectively, to monitor the enforcement of international ecological treaties and may provide in the longer run a clean source of energy.

A fourth driver of change, technology, was also considered, but it was not explicitly included in the assessment of the future demand for space assets because its main impact is likely to be on the supply side.

Following the blueprint outlined above, the next step would logically have been to define the scenario space and select the scenarios. However, because the complexities and uncertainties attendant upon each of these drivers cannot easily be reduced to one dimension in the scenario space, it would be extremely awkward to try to take all three drivers into account at once when building scenarios. In fact, a straightforward application of the blueprint outlined above would result in defining a multi-dimensional scenario space (*e.g.* eight dimensions if each driver is assigned two dimensions). Choosing appropriate dimensions for each of the drivers also calls for specialised expertise.

It was therefore decided first to ask outside specialists in the areas of each of the drivers to construct "driver scenarios" around each of the three drivers and draw the implications of each for the space sector. The three sets of scenarios developed in this way were then combined in-house into "synthesis scenarios".

To help ensure consistency among the three driver analyses, a common methodological approach and a standardised outline format were established. More specifically, the outside experts were asked to clearly identify five main steps:

1. Review of main trends and factors affecting "their" driver of change.
2. Identification of the main uncertainties affecting the driver.
3. Definition of the scenario space.
4. Selection and characterisation of the scenarios.
5. Creation of a table summarising the implications of the analysis for the future evolution of space applications.

The authors also agreed to adopt a common set of core assumptions (*i.e.* assumptions that remain unchanged across scenarios). Finally, as a further aid to consistency, the authors' first drafts were circulated to the Project Team and to the other authors for comment.

In constructing the synthesis scenarios, stylised versions of the experts' analyses were drafted, in which the steps outlined above are clearly identified and systematically followed. These stylised versions were then integrated into the synthesis scenarios. However, it should be noted that while the stylised versions are based on the work of the experts, they do not always reflect their work exactly.

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Chapter 3

Scenarios for the future of the space sector

This chapter sketches out the political, economic, social, energy, environment and technology consequences of each of the three synthesis scenarios presented in Chapter 2 and draws the implications for the future evolution of the main components of the space sector (military, civil and commercial).

Introduction

This chapter fleshes out the alternative future visions of the world implied by the synthesis scenarios constructed in Chapter 2, and their implications for the evolution of the space sector are assessed. For each scenario, the political, economic, social, energy, environment and technology features are sketched out and the consequences for the military, civil and commercial components of the space sector are explored. For civil space, two main aspects are addressed: the impact on space exploration and science and the impact on the expansion of the civil space infrastructure. For commercial space, attention focuses on the impact of the scenario on the business environment facing space actors, the expansion of the commercial space infrastructure and the development of the space industry.

Scenario 1: Smooth sailing

What the future holds

Introduction

This scenario points to a global world order under the benevolent guidance of international organisations in which free markets and democracy gradually become the accepted universal model for national institutions. Major contributing factors include the growth of global trade as well as the internationalisation of production worldwide. Other significant trends are progress in transport and communications and growing interest in global issues. In a favourable economic climate, international co-operation contributes effectively to solving world problems, including the alleviation of poverty. However, the environment continues to deteriorate, despite growing concerns in this regard. Moreover, various groups that feel left out or oppose the established order on ideological grounds resist what is perceived as the "westernisation" of the world. Such opposition is reflected in the persistence of terrorist actions by transnational groups, which may use "states of concern" as a strategic base for training recruits and planning actions against their enemies. Organised crime continues to be active, taking advantage of a more open world. Both groups have access to weapons of mass effect (WME) and use them to blackmail the more vulnerable governments.

Main features

Political: On the political front, a strong spirit of co-operation emerges at international level as countries realise that, in an increasingly inter-related world, independent action is more and more constrained and that the international community can quickly penalise opportunistic behaviour. The costs of being ostracised are high, and international public opinion carries great weight. The United States, the European Union, Japan, Russia, India and China have good relations. However, they still face the threat of the use of WME by terrorists and criminal groups. They respond by strengthening their own security and by increasing their co-operation with other countries in this area. The European Common Foreign and Security Policy is reinforced to allow Europe to strengthen its ability to act independently on the international stage. Close co-operation is maintained with the United States on security matters.

Economic: On the economic front, rapid progress in a broad range of technologies fosters high rates of growth worldwide, particularly in developing countries which gradually catch up with the West. The spirit of co-operation that prevails in international relations is reflected in a strengthening of World Trade Organization (WTO) discipline, despite occasional setbacks, notably in sectors of particular importance for the developing world, such as textiles and agriculture. Moreover, international agreements regarding the protection of intellectual property are reached, as a number of middle-income countries become net creators of information-intensive products and services (*e.g.* software in India). Foreign direct investment (FDI) is better protected, as a growing number of developing countries realise that it provides technology transfer opportunities as well as extra investment. In this rapidly globalising world, demand for transport and communication services increases substantially. There is a huge demand for educational services, as unprecedented numbers of individuals enter the labour force in the developing world. Substantial efforts are made to upgrade agricultural practices in response to a rapid and massive rural exodus in most developing countries.

Social: Growing prosperity helps to reduce the adverse consequences of demographic trends. In the developed economies it provides the resources to deal with the costs associated with an ageing population, while in developing countries it generates job opportunities for the rapidly growing labour force. As a result, migration flows from the South to the North increase only moderately, and more jobs move to the South. International co-operation and economic prosperity also provide the basis for dealing more effectively with poverty and malnutrition and for developing more effective programmes for coping with pandemics as they emerge. Rapid urbanisation calls for major

investments in infrastructure, and more effective public health and public education programmes are put in place.

Energy: Rapid economic growth results in an increase in the demand for energy, notably in large developing countries such as China and India. However, international tensions over energy remain within reasonable bounds as alternative sources of energy (*e.g.* tar sands, renewables) are developed and as market and other mechanisms promote more efficient use of energy. As a result, the price of energy increases only moderately. However, it is not easy to meet rising demand, and considerable efforts must be made for exploration and extraction as well as for bringing fuels to markets. Substantial resources are also devoted to developing clean energy technologies.

Environment: With economic growth, environmental problems tend to increase in the short to medium term. However, as a growing number of countries reach medium-income status, efforts to clean up local pollution accelerate and more countries are willing to impose limits on their greenhouse gas (GHG) emissions as long as other countries do so as well. The European Union takes the political lead in seeking binding solutions to global environment problems. A new GHG emissions abatement treaty based on the Kyoto Protocol is put in place with a comprehensive verification mechanism designed to ensure effective compliance.

Technology: Advances are made in a broad range of technologies (information technologies, biotechnology, nanotechnology). They spur economic growth and also provide new ways to deal with environmental problems (*e.g.* new pollution abatement techniques, more cost-effective renewables and developments in carbon sequestration). Rapid diffusion of new technologies to the developing world is particularly effective in helping these countries catch up with the West. However, effective technology transfer requires appropriate training facilities to upgrade workers' skills in receiving countries and help them keep up with innovations. Technology is increasingly developed at international level, with research teams making extensive use of teleconferencing and other communications technologies to maintain contact with their colleagues around the world.

Implications for the space sector

In the wake of better international relations, this scenario places less emphasis on military expenditures although the use of military space assets increases. Major progress is achieved in applying space technology to the solution of global social and environmental problems. Commercial space also expands significantly in a more open business climate.

Military space

A more peaceful world puts less priority on military expenditures. Military space budgets decline overall. However, space-faring countries outside the United States devote relatively more resources to military space as they strengthen their network centric warfare capability (the configuration of armed forces in which all units as well as individual soldiers are interconnected by a multi-layered communications network which enables commanders to monitor action on the battlefield and give orders in real time). Particular attention is devoted to developing a military space infrastructure in the areas of telecommunications, Earth observation (EO) and navigation for carrying out intelligence, communications, command and control (IC3) functions.

As tensions among the major space powers diminish, they increase co-operation to cope with the threat represented by states of concern and terrorist groups. In the short term, the major space-faring countries:

- Agree to adopt a revised anti-ballistic missile (ABM) treaty to acknowledge the need for national or multinational defence systems, but to limit these to ground-based interceptors with space-based sensors to detect and track incoming missiles.
- Develop at national and multinational levels better capability to monitor the activities of states of concern and terrorist groups. While space assets are part of the monitoring system, the role of unmanned vehicles (UVs) increases significantly.

In the medium to long term, the major space-faring countries agree to collaborate on the development of regional missile defence systems, as required. At the same time, the United States speeds up the development of a hypersonic cruise vehicle (HCV). Europe follows suit in collaboration with Russia.

Civil space

In this scenario, all of the world's major space-faring countries co-operate actively on the development of all aspects of civil space, including space exploration and science, basic R&D for the development of space technology as well as on the expansion of space infrastructure.

Space exploration and science. An increasing number of countries, including China, India and Brazil, decide to contribute to the International Space Station (ISS). Russia, Europe, Japan and the United States work together to develop an orbital space plane (OSP) for servicing the ISS.

An international consortium is created to develop an ambitious extra-terrestrial exploration programme, with missions to the Moon and to Mars.

By 2020, a permanent international station is established on the Moon. In 2025, the first manned mission to Mars is launched.

At the same time, all main space agencies co-operate actively to achieve progress in propulsion and to develop new satellite platforms.

Development of civil space infrastructure. The positive political and economic climate provides a good basis for strengthening international co-operation to deal with the world's principal social problems. The merit of space-based solutions is increasingly recognised and the International Space Agency (ISA) is formed to facilitate such efforts.

With the help of pioneering countries such as India, the World Health Organization (WHO) actively supports the use of telemedicine in the developing world as a way to achieve its goal of "health for all in the 21st century". At the same time, an effective system for dealing with pandemics modelled on the IC3 military concept is put in place worldwide.

The WHO joins forces with the United Nations Educational, Scientific and Cultural Organization (UNESCO), the International Labour Organisation (ILO) and ISA to promote distance learning as an effective way to reduce educational inequalities and facilitate the education of the rapidly growing working age population in developing countries. Private Western firms that invest heavily in these countries participate as well. The education ministers of a core group of countries decide to create a new intergovernmental organisation, EducSat, with the aim of providing tele-education services in participating countries. Membership in EducSat gradually increases as more countries recognise the merits of tele-education.

The Food and Agriculture Organization (FAO) increases its efforts to promote more efficient use of natural resources worldwide. Space assets are widely used for monitoring crops, for pest control and for precision farming. Because space-controlled precision farming has a lighter environmental footprint, the Global Positioning System (GPS) and Galileo are used to oversee the production of "green" agricultural products, with a view to satisfying more efficiently the growing demand for "organic" products.

Collective efforts to curb GHG emissions, undertaken largely under the initiative of the European Union, create a demand for space-based technologies to track emissions. The Kyoto Protocol is followed by the creation of a world environment protection agency which sets up a space-based system for monitoring the enforcement of environmental agreements in co-operation with ISA.

Commercial space

In this more peaceful world, major progress is made towards the creation of a more open environment for commercial space. The space infrastructure that supports trade and commerce is significantly upgraded. Taking advantage of liberalisation and the emergence of new business opportunities, the space industry undertakes broad restructuring at the global level. This paves the way for significantly reducing the cost of access to space and for developing new and innovative space-based services that can fully exploit the advantages that space offers over terrestrial alternatives.

Creation of a more open business environment. With regard to the institutional environment governing commercial space, progress is achieved on several fronts:

- WTO discipline is extended to a broad range of space products. Space firms, like other businesses, can benefit from new international rules regarding the treatment of FDI.
- UN conventions on space are reformed to provide clearer definitions, to clarify responsibilities regarding activities related to the launching, operation and disposal of space objects, and to better reflect commercial property rights.
- The role of the International Telecommunications Union (ITU) in allocating frequencies and orbital slots is strengthened. Appropriate rules ensure that such allocation is both efficient and fair. The rights and obligations of operators are clarified.
- All space-faring nations adopt national space legislation that conforms to a uniform or model code so that definitions, liabilities and property rights can be easily determined.
- The UNIDROIT Cape Town Convention on moving assets is ratified by a large majority of countries. This puts the financing of space assets on a much sounder business basis.

Significant progress is also achieved regarding the liberalisation of information flows:

- Mutually agreed rules are established for regulating e-commerce and transborder data flows.
- The regulation of operators of space assets is harmonised across jurisdictions, and applications procedures are significantly simplified. Foreign ownership rules are eliminated across the board.

Restrictions regarding space technology are relaxed. Major space-faring countries agree to ease restrictions on foreign investment, export controls and technology transfers among themselves. At the same time, they put in place

clear rules designed to deny access to sensitive technology by states of concern or terrorist groups.

The expansion of the space infrastructure. The favourable institutional context provides a good foundation for the extension of the space infrastructures that support the development of trade and commerce worldwide by:

- Developing a global broadband telecommunications infrastructure for which space assets play a role not only in trunking but also in "bridging the last mile", *i.e.* in connecting end users, in competition with terrestrial networks. In this more open world, the ubiquity space offers is a major selling point for space-based solutions.
- Developing a truly global positioning and navigation infrastructure for civil and commercial use that ensures full interoperability of several existing regional systems. The infrastructure is used for all modes of transport and greatly facilitates the expansion of civil aviation worldwide in particular.
- Developing a comprehensive global EO infrastructure that can be used for civil security as well as commercial purposes.

The development of the global space infrastructure helps to boost productivity not only directly, because of the services it provides, but also indirectly, by forcing a harmonisation of standards at the global level.

The development of the space industry. Space firms are able to restructure globally to take full advantage of economies of scale and scope, and Russian and Chinese firms play a growing role in this process. Some of these firms become the linchpins of large space consortia that operate globally and compete directly with their Western counterparts. New firms from emerging space-faring nations, notably India, Brazil and Israel, enter the industry.

Space firms engage in fierce competition. Major efforts are made to cut costs and improve the quality of services. Large R&D budgets are devoted to developing innovative space products. Some firms attempt to reduce competitive pressures through consolidation, but such initiatives are constrained by the action of antitrust authorities.

As a result of industry efforts and the expansion of commercial space, the cost of access to space is significantly reduced. In particular, the cost of manufacturing launchers is cut drastically and major advances are made in the manufacture of micro- and nano-satellites. Space tourism starts to develop after a small firm wins the X Prize in 2005 (The prize contest calls for launching a manned craft able to carry three people to 62 miles and return it safely to Earth twice within 14 days.) Space tourism starts first on a suborbital basis and then on an orbital basis in the 2020s. Advances on the commercial side eventually converge with the progress made by the military in developing an HCV, leading towards the end of the period to the emergence of a true reusable launch vehicle (RLV).

Scenario 2: Back to the future

What the future holds

Introduction

In this scenario, three major economic powers dominate the world: the United States, Europe and China. The United States remains the main power for a while but its leadership position is gradually eroded because of its relatively lacklustre economic performance. It is challenged by a rapidly growing China, which becomes increasingly confident, rejects Western values and is eager to regain, with the support of the Chinese diaspora, its historical status of "middle empire", which it considers its rightful place in the world. Russia plays an important supporting role for China, as Russian authorities also tend to resent Western criticism. Europe remains an economic giant, but it looks inward and its institutions are weak, as the extension of the EU to 25 countries has considerably slowed further integration efforts. In the face of the assertive coalition of China and Russia, Europe strengthens its ties with the United States and enhances and co-ordinates its military forces. A bipolar world gradually emerges, in which rivalry between the two blocs dominates the policy agenda in all major spheres of activities. Tensions are particularly high with respect to access to energy and other resources, as China becomes a major importer of energy and food.

Main features

Political: International tensions result largely from China's deep-seated differences from other major powers. After centuries of domination and humiliation, China is particularly keen to take advantage of its newly acquired economic strength to promote its national interest forcefully, at both regional and global levels. Territorial disputes with its neighbours are exacerbated and it takes an increasingly confrontational posture with the United States and the West in general, notably regarding access to energy and natural resources. Russia, in reaction to Western criticism, creates stronger links with China. The economies of China and Russia become increasingly complementary (*e.g.* Russia sells natural resources and technology to an increasingly prosperous but resource-poor China), and they share control of Central Asia. In the face of this challenge, Western countries remain united. Europeans and Americans remain conscious of their shared political ideals, cultural heritage and economic system, despite occasional differences of opinion. Both blocs respond to growing tensions, such as the situation of Chinese Taipei, by strengthening their military capability. Security concerns are high on policy

agendas. The North Atlantic Treaty Organization (NATO) is strengthened. More resources are devoted to military budgets, notably in Europe, which implements its own network centric warfare concept. Transatlantic co-operation is enhanced on security matters, in terms of intelligence and counter-intelligence capability. Restrictions on the transfer of sensitive technologies are tightened. Efforts are also made by Western countries to foster co-operation on military matters with India.

Economic: Sluggish economic growth prevails in the West, owing in part to the inability of the United States to deal effectively with its trade deficit and debt burden, while Europe and Japan are unable to undertake the structural reforms necessary to spur growth (*e.g.* financial markets in Japan, labour markets in Europe). In contrast, China enjoys high sustained rates of growth; the authorities are able to reform financial institutions, privatise public enterprises and promote growth in inland provinces. They do so with a view to maximising their country's national power in the long run, rather than because they adopt liberal ideals. China's rising prosperity results in a large increase in its demand for food and natural resources, including oil. This demand is met partly through co-operation with Russia as Russia's economy gradually becomes integrated with the Chinese economy. China's efforts to capture a larger share of supplies outside Russia result in confrontations with the rest of the world, notably the West. Western governments retaliate by closing their markets to Chinese goods, with the result that the world economy is broken into rival blocs. This helps to spur economic development in other developing countries, which benefit from the diversion of trade and investment to them. World growth slows overall. The security concerns noted above extend to the economic sphere, and firms are increasingly concerned about the security of their assets abroad. The movement of goods and people continues to increase but tends to be concentrated within the two blocs.

Social: Slow economic growth in the West exacerbates social tensions, including between generations. In the face of growing budget deficits, major efforts are made to improve the efficiency of welfare systems, notably the healthcare system. Immigrants from the South are viewed with greater hostility. In the face of these tensions, more emphasis is placed on law and order in ageing societies that feel increasingly vulnerable. Isolationist sentiment in the United States remains subdued as a growing number of Americans realise the need to co-operate more actively with Europe in the face of China's increasing strength. Social tensions in the South are alleviated by the economic boost caused by the diversion of trade and investment to them.

Energy: Heavy dependence on fossil fuels continues. Although adverse events due to climate change occur, the main priority remains high growth, low energy prices and stable supply, in both the West and the rest of the world.

China takes advantage of its closer links with Russia and Central Asia and boosts its investment in nuclear energy as well. Concerns about security of supply rise and major efforts are made to develop alternative sources of energy.

Environment: As international tensions increase, hopes of reaching an international agreement on the control of GHG emissions vanish. The environment deteriorates. However, co-operation to deal with local pollution problems increases at regional level. A series of pollution abatement treaties is implemented between neighbouring countries.

Technology: The rate of innovation in the West is adversely affected by poor economic conditions. Technology transfers to the South are largely directed towards Western-friendly nations. Priority is given to military research, including surveillance and communications technologies, biotechnology, nanotechnology, artificial intelligence (AI), robotics and WME.

Implications for the space sector

For the space sector, the confrontation between China/Russia and the West leads to the emergence of three main co-operative blocs: North America-Europe-Japan, China-Russia and India-other emerging space actors. Closer links between North America and Europe result in an integrated space industry. Space firms benefit from higher military space budgets but suffer somewhat from a less open trade and investment climate. Civil space largely devotes its efforts to reducing the cost of the welfare system through the development of dual-use technologies, while prestige activities are designed to strengthen "soft power".

Military space

Growing tensions between the West and China/Russia lead eventually to a new type of space race and the gradual "weaponisation" of space. This involves the deployment of ground-based national missile defence systems, including advanced surveillance and warning systems, first by the United States and then by other major space-faring countries. The increasing weaponisation of space is also reflected in the development of anti-satellite (ASAT) systems, including airborne and ground-based lasers and parasitic satellites, and finally the deployment of space-based lasers capable of attacking both missiles and satellites towards the end of the period.

EU countries strengthen their common security and defence policy. Military space plays a central role and a core group of like-minded countries agree to co-ordinate their military space programmes so as to minimise duplication. This leads to the rationalisation and development of Europe's military space infrastructure. The Europeans want to establish an

independent space capability, but they also stress interoperability with US military space-based assets. The military space industry of the United States and the EU becomes increasingly integrated.

China gives high priority to the modernisation of its armed forces, with the support of technology transfers from Russia. It views the use of space as being of central importance and paving the way for its own network centric warfare concept. Military build-up by the two main blocs encourages other countries to enhance their military space capability, in particular India. The demand for communication and EO satellites increases.

Civil space

Because of international rivalries, a large share of civil space budgets is devoted to projects likely to create "soft power" in the form of additional prestige at home and abroad or as a way to strengthen or extend international influence. This environment is particularly favourable to new exploration programmes, technological developments and space-based responses to regional social demands (*e.g.* telemedicine).

Space exploration and science. Countries step up their respective exploration programmes for reasons of prestige.

Because of political tensions and miscommunication, Russia abandons the International Space Station programme. It is at first maintained as an expensive orbital laboratory with US, European and Japanese participation.

The United States, Europe and Japan launch an ambitious unmanned Mars exploration programme, while phasing out the ISS. The objective is to put humans on the red planet by the mid-21st century. Following some European efforts in the early 2000s, Japan initiates a lunar project, starting with the Lunar A and Selene projects, to survey the Moon's resources and prepare further exploration of the Moon.

China also initiates an ambitious Moon project, starting with an unmanned lunar probe. Russia's unparalleled experience with long-duration human spaceflight gives China an edge over the West. The official long-term goal of both China and Russia is to exploit the Moon's potential mineral and energy resources for the benefit of humanity, and the short-term goal is to increase their national prestige, both at home and abroad. By the end of the 2030s, China and Russia establish a manned outpost on the moon.

India, with an unmanned mission to the Moon by 2008, is not far behind. The mission's aim is to showcase the country's scientific capabilities, to excite the younger generation and to increase national confidence. Going to the Moon is also perceived as an important step strategically and economically. It is a way to make India's voice heard, as it was after the nuclear weapons tests at Pokhran in May 1998. Moreover, India does not want to be left behind when human beings colonise the lunar and Martian surfaces in a few decades. India promotes co-operative space projects among developing countries, including Indonesia, Iran and Brazil. This increases the number of New Delhi's potential partners, while it strengthens its independence from both the West and the China-Russia axis.

Following the Indian model of space development, many countries place special emphasis on projects using small satellites and available technology to perform specific economically useful missions.

Development of civil space infrastructure. In this period of high social demand, space applications increase and provide government-sponsored solutions. New dual-use technologies are developed.

In the face of escalating healthcare costs, telemedicine offers an attractive way to deliver health services, notably homecare services to the elderly, by taking advantage of the direct-to- home (DTH) broadband capability already in place in many homes. In this way, the health status of the elderly can be continuously monitored. Tele-consultations can be made with the assistance of nurses specifically trained for this purpose. Substantial savings are realised as costly and time-consuming home and hospital visits are cut to a minimum. Other civil space efforts focus on the environment. Although little progress is made regarding the abatement of GHG emissions, the two main geopolitical blocs vie for the allegiance of developing countries by contributing to efforts to monitor pollution via satellite and providing emergency services in case of major natural disasters. Moreover, space assets are used to verify the application of regional pollution abatement treaties.

Recommendations to avoid more orbital space debris are regularly presented to existing multilateral bodies by developing countries, but little progress is achieved because the guidelines enacted are not enforceable.

Concerning technology development, significant advances in AI, robotics and nanotechnology contribute to cut the cost of space missions, as in scenario 1.

Private actors develop suborbital launchers, and governments fund space-plane technologies as a priority for military purposes.

The end of the 2030s sees the development of energy relay satellites developed through co-operative regional efforts involving energy companies and governments. Some security concerns, in particular the vulnerability of such systems to ASAT weapons, limit their use.

Commercial space

In a tense international situation, where regional blocs tend to pursue their own strategic interests, commercial space activities tend to develop more slowly than in the first scenario. A limited but real return to protectionism in the space sector is encouraged by security concerns. Each bloc develops commercial applications to meet its own strategy.

The business environment. In this scenario, internal space markets are largely protected, and many advances mentioned in scenario 1 do not take place. Technology transfers between blocs face high regulatory hurdles.

The UNIDROIT Convention is finally approved, but only in Western countries.

A North Atlantic Free Trade Agreement is established between North American Free Trade Agreement (NAFTA) countries and the EU. A number of Latin American and North African countries are associated to the agreement. This helps to create a more open trading environment across the Atlantic and fosters the development of space applications to some extent. However, the emphasis on military space tends to slow the development of commercial space, as space firms devote a higher proportion of their resources to military contracts.

In China, the two-track space strategy adopted in the first decade of the 21st century (establishing joint ventures with Western firms and participating in major co-operative efforts) allows it to expand its technological expertise and know-how and to gain commercial space independence (*i.e.* the ability to offer space products and services without first obtaining agreement from Western providers of key components) before breaking with the West. China's increasing co-operation with Russia and some Association of Southeast Asian Nations (ASEAN) countries permits it to export space-based services (*e.g.* space imagery, access to telecommunications satellites) to the rest of the world. As a large country with limited infrastructure, it finds satellite transmission a useful way to develop a nationwide telecommunications network quickly. China is also keen to use space imagery to find and manage natural resources and to export its competitively priced space products to the rest of the world. Because of growing international tensions, China is forced to target its exports to countries outside the Western free trade region and to compete with other important emerging players (*e.g.* India), as Western firms are subjected to stricter export controls on space assets and components considered strategic by military experts

Limited expansion of the commercial space infrastructure. Many new space-related products and services are developed regionally. However, export and investment restrictions tend to reduce the broad diffusion of new technologies and applications.

Restrictions on information flows (*e.g.* Internet regulations, operator licensing) negatively affect the telecommunications sector and the development of "infocom" applications in some countries. The broadcast industry (*e.g.* television via satellite) faces strong regional competition from cable operators.

The use of space-based navigation systems is widespread for all forms of transport, and notably for civil aviation. This situation forces developers of navigation systems (United States, Europe, China, Russia) to co-ordinate their efforts and to discuss interoperability issues.

The growing demand for energy results in further exploration (*e.g.* oil, gas) and greater need for appropriate space-based technologies. In this regard, the improved hyper-spectral capability of remote sensing proves to be particularly useful for oil exploration. Space assets are also used extensively to monitor pipelines and to assist in major energy infrastructure projects, which are needed to meet the rising demand for energy. However, rivalry between the blocs results in substantial duplication of effort.

A new commercial sector, suborbital space tourism, sees some limited development, especially in the West. Enthusiastic private industries develop suborbital launchers with off-the-shelf dual-use technologies, but the tense international security environment restricts their commercial activities (*e.g.* launch conditions, number of flights per year). Based on the commercial success of new adventure tourism activities, some companies seek to use the new military space-plane technologies.

The development of the space industry. In the United States, Europe and Japan, semi-private space firms further integrate their activities and take advantage of higher military budgets to develop dual-use applications under public-private partnerships. In their own markets, they are able to gain some protection against cheap imports from other players (*e.g.* China, Russia, India).

In each bloc, space companies compete with each other, but they also all face strong competition from regional terrestrial systems.

Scenario 3: Stormy weather

What the future holds

Introduction

Strong disagreements among major powers lead to a gradual erosion of international institutions. In response to sharp criticism of its interventions on the international scene, the United States acts increasingly unilaterally,

withdraws from any military action not justified by an effective threat to American vital interests and decides to deploy an anti-ballistic defence system to protect the US territory against limited ballistic attacks. As it largely withdraws from the international scene, ethnic conflicts multiply leading to massive migrations and terrorism. A growing number of countries acquire a nuclear capability, increasing the potential for devastating conflicts at regional level, notably in Asia and in the Middle East. Economic conditions deteriorate as the world reverts to protectionism. Growing social and ecological problems are largely ignored as international co-operation is replaced by bilateralism driven entirely by short-term *realpolitik* considerations.

Main features

Political: Confronted with terrorism and other threats to its national security, the United States becomes increasingly impatient with international rules which it perceives as constraining unduly its national sovereignty, notably its ability to protect its vital national interests as it sees fit. Public opinion is increasingly hostile towards the United Nations and towards countries that attempt to restrain unilateral US actions and becomes increasingly isolationist. This contributes significantly to undermining the authority of the UN, to encouraging a growing number of larger countries to ignore their international obligations and to fuelling tensions between the United States and other countries, including its European allies, thus undermining the transatlantic alliance. NATO ceases to be an effective body and is eventually abolished. The multilateral regime gradually erodes and a confusing web of *ad hoc* and shifting partial agreements/alliances among like-minded countries emerges. The Europeans, Russians, Chinese, Japanese and Indians decide to increase the resources devoted to their defence capability. These countries make some efforts to increase co-operation. This leads notably to closer relations between Russia and India on the one hand, and between Europe and Japan on the other. However, co-operation remains limited and does not lead to meaningful integration of defence capabilities.

Economic: The breakdown in the multilateral regime is reflected in a gradual erosion of WTO discipline. When confronted with economic difficulties, countries do not hesitate to adopt "beggar thy neighbour" policies, thereby provoking retaliatory actions by their trading partners. As a result, the liberalisation process initiated after World War II gradually comes to a halt. Tariff and non-tariff barriers rise, flows of FDI dry up and the globalisation process is gradually reversed, triggering a series of economic and financial crises.

Social: Political tensions and economic difficulties are reflected in serious social tensions in both the West and the rest of the world. Security concerns move to the top of the policy agenda. Poverty is on the rise in the South, and migratory flows to industrialised countries increase significantly, further exacerbating these countries' social and political problems. Foreign aid is considerably reduced, leaving large regions of the world in dire poverty (*e.g.* Africa).

Energy: Slower growth tends to moderate the increase in the demand for energy. However, security of supply is of primary concern for most countries, thus exacerbating tensions among energy-importing countries. This also helps to spur efforts to find alternative sources of energy.

Environment: Protection of the environment is low on the policy agenda of most nations, given high public concern about national security, economic development and security of the energy supply. Some efforts are made to reach an agreement regarding the capping of GHG emissions, but as a result of international tensions and lack of public support the negotiations are scuttled. Pollution abatement measures are taken at national level in OECD countries, as well as in some medium-income countries. Some international agreements are reached for dealing with transborder pollution.

Technology: Depressed economic conditions are reflected in a relatively low rate of innovation, except in the field of military technology, and in slower diffusion of new technologies to developing countries.

Implications for the space sector

Under this scenario, security, defence and other strategic government uses of space become increasingly important. Most space powers tend to develop their systems independently, forming alliances as needed, but this is a divided world with no clear alliances. Civil space tends towards dual-use technological developments or activities that contribute to enhance soft power. However, the value of the space infrastructure for the effective and efficient delivery of social services is increasingly recognised in major space-faring countries. The impact on space business is mixed. On the one hand, space firms benefit from government contracts and the spin-off opportunities they offer. On the other hand, markets become more fragmented, export controls more stringent and the restructuring of firms at international level is stifled by national security considerations.

Military space

In a world perceived as increasingly hostile to the vital national interests of important space powers, the military space budget increases worldwide.

In the United States, although specific programmes are modified by successive administrations, efforts to militarise space win out. The United States decides in the early 2000s to carry on with its anti-ballistic programme, as the abandonment of the ABM treaty in June 2002 effectively removed

restrictions on placing weapons in space. The US ABM programme involves the successive development and deployment of ground-based and sea-based interceptors, space-based kinetic hit-to-kill systems, airborne lasers (ABL) capable of destroying most low Earth-orbit satellites and finally a constellation of space-based lasers (SBL), capable of intercepting 94% of all missile threats in most threat scenarios. SBLs can also be used as anti-satellite weapons. It should be noted that competition from terrestrial military systems (*e.g.* drones) does not stop the development of space military systems.

The United States steps up its efforts to develop an unmanned reusable hypersonic cruise vehicle capable of reaching speeds of Mach 10-15 and of placing ordnances on military targets anywhere in the world within a few hours. The HCV becomes fully operational in the late 2020s for military purposes. In addition to striking targets around the globe, it can also be used for launching short-term satellites to bolster communications, or for remote sensing or navigation in a target region. Smaller versions of the HCV are developed.

Following the US lead, a growing number of countries decide to develop or strengthen their own military space assets, including for communication, Earth observation and navigation.

After a series of lengthy discussions, Europeans finally launch a major military space programme by the end of 2010s. The programme is designed to reduce the large and growing gap in military space capability with the United States and to keep up with the efforts of other major space powers, notably China. Europe develops this full-fledged military "system of systems" for space activities to ensure its independence and its autonomous and informed decision-making.

Another major subject of debate is whether Europe should develop its own ABM system, and if so, whether it should do so independently or in co-operation with either the United States or Russia. This is a subject of strong disagreement between Atlantists and Continentalists. Finally, an independent route is chosen.

China also gives high priority to strengthening its military space capability over the period, owing to its volatile partnership with Russia. In response to US missile defence deployment, China develops and ground-tests an advanced anti-satellite weapon. It also strengthens its effort to develop a ground-based laser.

Russia tends to use its industrial and scientific know-how to partner with the most promising ally in military space activities. Its numerous military exports allow it to develop, in a limited way, new technologies, especially in propulsion, which are of great interest to one-time potential partners (*e.g.* China, Europe).

Civil space

Because of the depressed economic conditions, there are strong pressures on discretionary budgets, notably on programmes that are not perceived as being of immediate benefit.

Space exploration and science. No major common international exploration programmes are pursued, as national and regional programmes remain in the forefront.

Space agencies undertake strategic co-operative efforts, essentially to take advantage of and to influence the research efforts of other nations. However, some efforts backfire and/or conflict with strategic objectives. For instance, the ISS programme stalls by the late 2010s, as concerns in the US Congress about technology transfers to Russia result in budget cuts for this activity. This leads eventually to a winding down of ISS activities in a climate of mistrust.

Some countries try to strengthen their soft power through a number of spectacular initiatives designed to demonstrate their space prowess to the world. As in the second scenario, these efforts largely take the form of competitive missions to the Moon and to Mars. However, the scientific value of these space ventures is undermined by duplication of effort and by the priority given to technology over science. Moreover, the missions are less spectacular in this scenario because available resources are significantly lower.

The expansion of the civil space infrastructure. Even though civil budgets are quite limited, some countries still recognise that civil space programmes are not just a cost item but can sometimes be considered an investment that contributes significantly to their development.

National civil space research efforts are largely devoted to the development of dual-use technology. This applies notably to meteorology, Earth observation, telecommunications and navigation systems as well as to launchers.

From a strategic perspective, the Europeans view Galileo as a key component of their space infrastructure. Galileo helps to ensure that Europe is present on the international scene in all aspects of cutting-edge technologies and allows it to shake off dependence on the US GPS. Galileo's strategic dimension is underscored by the creation, in addition to the civil supervisory board, of a separate security supervisory board. The continued interoperability of some space systems (*e.g.* navigation constellations) with those of the United States, Russia and China, is the source of heated disputes.

China and India, large countries with limited terrestrial infrastructure, lead the world in the development of space-based telemedicine and distance education applications and are able to export their expertise to other developing countries in Asia, Latin America and Africa. The Indian model of autonomous space development inspires many emerging space powers (*e.g.* Brazil, Turkey).

In Europe and North America in particular, the development of DTH offers a convenient and cost-effective platform for applications designed to reduce the digital divide and to promote home healthcare services outside major urban areas in order to alleviate the growing pressure on healthcare budgets.

Commercial space

Government attention to military space has some positive effects on commercial space. However, those effects are offset, in part, by the deleterious consequences of poor economic conditions and market fragmentation.

The business environment. As in scenario 2, protectionism tends to be quite strong, limiting technology transfers and export possibilities.

Some selected lucrative export markets for space products and services remain open, as a growing number of countries are keen to build a space capability and to acquire the necessary technology from major space powers. Such powers agree to do so for selected countries for strategic reasons and to extend their regional influence.

Private investment in space is cut back, as high-risk investment opportunities requiring the raising of large up-front capital are the first to be postponed when economic conditions are depressed. The poor investment situation is partly offset by the decision of a number of governments to purchase space services directly from private sources rather than to create them within government agencies. However, of necessity, these profit opportunities are heavily regulated and dependent on the budget process.

Limited expansion of the commercial space infrastructure. On the positive side, advances for military space provide spin-off possibilities for civil and commercial space applications. However, little progress is made in developing other segments of commercial space.

Strong regional barriers to information have very damaging impacts on telecommunications services (*e.g.* television via satellite, Internet).

Some space assets (*e.g.* remote sensing, navigation systems) are used extensively for monitoring the production and distribution of oil and gas (navigation and Earth observation systems). Substantial exploration also takes place in some countries anxious to reduce their dependency on imports.

In the launch sector, the early development of a civil and commercial version of the small launch vehicle (SLV) and of the HCV gives the United States a strong comparative advantage for launching small satellites towards the end of the 2020s. However, protectionist measures in other countries prevent the US industry from fully exploiting its technological advance. This does not prevent a number of less developed countries (LDCs) from taking advantage of the cheaper launching fees offered by US firms to send their satellites into space.

Suborbital space tourism develops more slowly than in scenario 2, amid strong international tensions. The general environment of distrust and the dual nature of launchers strongly limit space tourism's commercial possibilities.

The development of the space industry. As in scenario 2, most space companies face strong internal competition in their respective regions. The relative progress in space technologies, due to the high priority accorded to military space, gives space operators an edge over their terrestrial competitors in some cases (*e.g.* surveillance systems). This helps commercial providers of space-based services to maintain revenues in a depressed market. However, space systems in direct competition with terrestrial alternatives (*e.g.* cable operators) suffer major losses of revenues, as markets become increasingly fragmented.

Conclusion

The three synthesis scenarios presented here provide very different future visions of the world, ranging from the optimistic outlook of "smooth sailing", which foresees major advances to improve human conditions in a spirit of international co-operation, to the dark picture depicted by "stormy weather", which sees a world caught in a vicious circle of violence and where most of the major problems facing humanity today (*e.g.* conflicts, poverty, malnutrition, disease, environmental degradation) become worse. Even the more optimistic scenario is not without its darker side, notably the rise of non-state actors increasingly capable of using WME in the pursuit of their cause, whatever it may be. Despite these differences, the scenarios share some common ground with respect to their impact on space.

Military space plays an important role in all three scenarios, although in different degrees. Even in the relatively peaceful world of *smooth sailing*, security concerns are high and a number of countries are anxious to strengthen their military space capability. This results in a strong and robust

demand for military and dual-use space assets worldwide, as well as substantial increases in military and dual-use R&D budgets for space outside the United States.

Civil space also plays an important role in all scenarios, although for different reasons. In *smooth sailing*, its role in fostering international co-operation to solve world problems (education, health, environment) is central. In *back to the future*, prestige projects and attempts to increase soft power give importance to spectacular ventures to the Moon or to Mars. Space is also called upon to solve world problems but in a less co-ordinated, more fragmented and less effective manner. Even in *stormy weather*, the outlook for civil space is not bleak, although the resources devoted to it may be quite low. As in the other scenarios, the development of dual-use technologies remains a priority; prestige and soft power are also important drivers. World problems are addressed in a more fragmented manner than in *back to the future*, but important gains can still be made if space firms are able to demonstrate that space solutions can bring about major savings for cash-strapped governments.

Commercial space varies much more than military space across the scenarios. It thrives in the *smooth sailing* scenario, remains strong in the *back to the future* scenario but is seriously constrained in the *stormy weather* scenario. It is worth noting that for space firms in Europe and the United States, scenario 2 may be the most favourable because of the protection it offers against competition from non-Western firms. In all three scenarios, commercial space benefits from military budgets for space.

Chapter 4 will discuss how the importance of space in the various scenarios may translate into a demand for space applications and draw from this analysis, taking into account the supply side, some conclusions about which applications may be considered "promising".

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Chapter 4

Implications for space applications

This chapter draws out the implications of Chapters 2 and 3 for the future development of space applications. Both the potential demand for such applications under the various scenarios and an assessment of their technical feasibility are considered. Applications that appear to be "promising" i.e. both attractive from a demand perspective and technically feasible at a reasonable cost, when compared to possible terrestrial alternatives, are identified.

Introduction

This chapter looks at the implications of the scenario-based analysis of preceding chapters for the future development of space applications and identifies potentially "promising" applications. It first considers the potential demand for space applications in terms of the various scenarios. It then examines supply-side considerations to assess the chances of meeting this potential demand. On the basis of this "reality check", a list of applications likely to be both in demand and technically feasible in the coming years is drawn up. As used here, demand takes into account private or "commercial" demand, "social" demand and military demand. It also factors in potential terrestrial alternatives to space-based solutions that may compete in the same markets. The analysis is essentially qualitative; no attempt is made to quantify demand.

When attempting to identify "promising" applications, their chronological development as well as the interrelations of applications along the "space value chain" must be considered. The space value chain is made up of three broad groupings of activities or services: information services, transport services and manufacturing (Table 4.1). In terms of the chronology, "weightless" applications such as information applications are likely to be developed first, given the high cost of access to space. Transport applications would follow since they rely heavily on information applications, notably for communication and navigation. Manufacturing/mining applications, which depend on the effective development of the first two groupings, would be expected to come last. The cost of access to space indicated in Table 4.1 is purely indicative; it is intended to give an idea of when a particular group of applications is likely to become commercially feasible. For instance, "space tourism" might start to become viable when the cost of access to space declines to USD 1 000/kg, assuming that the reliability of space flights increases by several orders of magnitude.

The following sections first consider how the implications of the scenarios for the three main components of the space sector affect potential

Table 4.1. **Broad categories of space applications**

	Sub-categories	Cost of access to space
Information services	• Communications • Earth observation • Navigation	~ USD 10 000/kg
Transport	• Public access to space • Space transport	~ USD 1 000/kg
Manufacturing	• Solar energy • Microgravity • Lunar extraction	~ USD 100/kg

Source: OECD.

demand for various space applications. Next, the technical feasibility of such applications is assessed, and the opportunities that further technological development may offer are considered. The concluding section presents a list of promising applications that emerge from the preceding analysis.

Potential future demand for information applications

Telecommunication services

The scenarios presented in Chapter 2 all suggest that overall potential demand for telecommunications should remain strong in a broad range of possible futures (Table 4.2). The development of broadband in the coming years (notably fourth-generation broadband) appears inevitable, although it occurs at different rates across scenarios and may involve different actors.

Table 4.2. **Summary of expected demand for telecommunications**

Scenario 1 Smooth sailing	Scenario 2 Back to the future	Scenario 3 Stormy weather
Expected demand: Given increasing liberalisation of the economy and growth in trade worldwide, significant expansion of demand for communications, particularly for broadband at domestic and international levels. Concerns about extending access to broadband.	*Expected demand*: Less expansion of demand than in scenario 1 because of constraints imposed by the bipolar arrangement but still large, particularly for broadband, within the major world regions. Shortfall made up in part by increased military-related demand.	*Expected demand*: International demand less than in scenario 2, but with a focus on broadband. Military demand probably equivalent to scenario 2.
Implications for space: Space in a very good position to capture a sizeable share of demand because of its ubiquity as an integral part of a global broadband network.	*Implications for space*: Role for space less important than in scenario 1 because of its reduced geographical advantage and perception that space assets may be more vulnerable.	*Implications for space*: Smaller role than in scenario 2, with even DBS under threat in some markets if they are too narrow.

Source: OECD.

Three main factors are at play. First, the overall rate of economic growth drives commercial and social demand for telecommunications services. Second, the degree of fragmentation of markets affects the relative competitive position of space-based solutions and their terrestrial alternatives. Third, the level of international tensions drives military demand for space-based telecommunications, notably broadband, in the context of the development of network centric warfare capability.

It follows that from a social and commercial perspective, space-based solutions are strongest in scenario 1 and weakest in scenario 3. In scenarios 1 and 2, space operators may be able to leverage their strong position in direct broadcast satellites (DBS) to extend their services to broadband users.

They are also well placed to provide the "last mile" solution for rural and remote areas and address the needs of individuals on the move. In scenarios 2 and 3, the relative decline in market demand is offset, at least in part, by an increase in military demand.

In all scenarios, the demand for mobile communications should be high. Space can capitalise on this if appropriate technical solutions are found. However, space telecommunications face serious terrestrial competitors and could largely lose out to fibre optics (or future terrestrial alternatives) in urban areas or for communications between urban areas.

Table 4.3 illustrates the potential growth of commercial and social demand for specific telecommunications services. Demand changes significantly in the three scenarios.

Table 4.3. **Growth of potential demand for space-based information services**

	Scenario 1 Smooth sailing	Scenario 2 Back to the future	Scenario 3 Stormy weather
Multimedia entertainment	High	Medium	Medium
International e-commerce	High	Medium	Low
Distance learning	High	Medium	Low
Telemedicine	High	Medium	Low

Source: OECD.

The existence of a genuinely ubiquitous broadband network will have far-reaching implications. First, it will have a strong positive effect on the economy. It may result in a significant boost to productivity and should foster the development of e-commerce. Applications in the fields of entertainment and e-commerce, already well established, may receive more income.

The trends towards a more mobile society and the increasing costs of transport are strong drivers in favour of distance learning and telemedicine, in both the OECD and the non-OECD areas. Their development could help to reduce the "medical divide" and the "digital divide" within and among countries. Even if economic growth slows (scenarios 2 and 3), these applications may remain attractive owing to their cost-saving features (*e.g.* extension of homecare services). Finally, large multinational enterprises (MNEs) are likely to take advantage of the opportunities that distance learning offers to train their staff and keep their skills up to date. The military will be interested in both fields of application. In this context, space-based solutions may play an important role, not only in rural and remote areas but also in urban areas, depending on how technology evolves. The increasing mobility of the population should also favour space-based solutions.

Conclusion for telecommunication services

Given the size of the untapped potential markets for telecommunications, the four main promising applications are, in decreasing order:

- Telemedicine.
- Distance learning.
- E-commerce.
- Multimedia entertainment.

Earth observation services

Earth observation (EO) is an aspect of space applications that is technologically mature and very valuable from the military, social and commercial perspectives. Many applications are being developed, building on specific tools and techniques, such as remote sensing imagery, geographic information systems (GIS), digital terrain mapping (DTM) and subsidence monitoring. Although alternative technologies (*e.g.* aerial observation) have progressed and new ones are in the wings (*e.g.* unmanned vehicles – UV), space-based observation has a unique capability to provide the "big picture" and is becoming increasingly flexible. Significant progress has also been made in the systems needed to exploit the data collected by EO satellites.

From a military perspective, EO is a critical component of intelligence, communications, command and control (IC3), notably the intelligence and control elements. For instance, it offers a unique capability to monitor the deployment of hostile forces or to provide in real time a picture of the progress achieved on a particular theatre of operations. EO has also proved to be an effective tool for monitoring the application of disarmament treaties.

From a civil perspective, EO has a wide range of applications in support of important public responsibilities, including security (natural disaster prevention and management, search and rescue missions), the management of natural resources, land cover and urban planning, weather forecasting and climate change monitoring (*e.g.* as addressed by the Global Monitoring for Environment and Security (GMES) programme).

From a commercial perspective, EO is of value to a growing range of businesses from insurance companies wishing to estimate the cost of a natural disaster to farmers who want to know the potential size of a particular crop or wish to apply precision farming techniques.

As Table 4.4 indicates, demand for Earth observation is expected to increase in all scenarios, although the composition of demand varies. For

Table 4.4. **Summary of expected demand for Earth observation**

Scenario 1 Smooth sailing	Scenario 2 Back to the future	Scenario 3 Stormy weather
Expected demand: Strong for civil, security and commercial applications in a broad range of activities. Systems likely to be regional or global and fully integrated.	*Expected demand:* Strong for military, security, civil and commercial use. Systems likely to be regional.	*Expected demand:* Strong for military and security, less important for civil and commercial. Systems tend to remain largely national.
Implications for space: A key role for space in association with other techniques (*e.g.* UV for more local observation). Space competitive because duplication of effort minimal.	*Implications for space:* An important role for space, perhaps not as cost-effective as in scenario 1 because of duplication. Increased military demand.	*Implications for space:* High military demand, high cost for civil and commercial demand because of duplication.

Source: OECD.

instance, military demand will likely be stronger in scenarios 2 and 3 than in scenario 1, while civil and commercial demand is likely to be stronger under scenario 1. Finally, applications related to strengthening domestic security (including dealing with natural and man-made disasters and extreme weather conditions) should be high under all scenarios. The main difference across the scenarios is the degree of international co-operation in the development of systems. They can be expected to be more international and complete in terms of coverage, hence more effective, in scenario 1 and to be more fragmented, involve more duplication and be less effective in scenarios 2 and 3 (Table 4.5).

The important public-good and commercial elements of Earth observation provide strong incentives to develop user-oriented applications

Table 4.5. **Potential demand for Earth observation applications**

	Scenario 1 Smooth sailing	Scenario 2 Back to the future	Scenario 3 Stormy weather
Meteorology	High	High	High
Oceanography, climate change	High	Medium	Low
Precision farming	High	High	Medium
Fisheries	High	Medium	Medium
Forestry management	High	Medium	Medium
Exploration (*e.g.* oil, gas)	High	High	High
Urban planning	High	High	High
Natural disaster prevention and management	High	High	Medium
Defence/security	Medium	High	High
Treaty monitoring (*e.g.* environment, disarmament)	High	Medium	Medium

Source: OECD.

over the next 30 years. Aside from the obvious military applications (*e.g.* surveillance), space observation can provide solutions to a number of key social and industrial problems:

- Demand for energy is expected to increase worldwide. A greater need for appropriate space-based exploration applications (*e.g.* for oil, gas) is probable, as remote sensing's increasingly improved hyper-spectral capability is well adapted to oil exploration.
- National, regional and/or international security-related programmes (*e.g.* weather, environment, disaster prevention systems) may be developed. There is significant potential demand for space-related applications for natural disaster prevention and management.
- Some treaty monitoring activities from space for environment and/or disarmament as well as for the verification of the application of national or regional policies (*e.g.* Common Agricultural Policy) could be put in place. In certain cases, space verification of agreements with billions of dollars at stake will be the only or the main tool for this purpose (*e.g.* enforcement of greenhouse gas [GHG] emissions abatement accords).
- Monitoring and management of land cover for urban planning, forestry management and agriculture will be an increasingly important task for local and regional decision makers, as well as commercial actors, who need to improve safety, profitability and the environment (*e.g.* formulation of land-use planning proposals, monitoring urbanisation, insurance assessments, precision farming).

Some of the relatively high potential demand for such applications could be met by terrestrial competition, as non-space systems (*e.g.* aerial photography) may also benefit from advances in electronics and other sectors and provide alternatives for some uses.

Conclusion for Earth observation

The most promising applications in the next 30 years (excluding military applications) may be:

- Environment applications (meteorology, oceanography, climate change).
- Land use management (*e.g.* urban planning, precision farming).
- Exploration (*e.g.* oil, gas).
- Natural disaster prevention and management.
- Treaty monitoring (*e.g.* environment, disarmament).

Positioning and navigation

Satellite radio navigation is based on the emission of signals from satellites that give an extremely precise indication of the time. With the use of a small cheap individual receiver, one can determine one's own position or the location of any moving or stationary object (*e.g.* a vehicle, a ship, a herd of cattle, etc.).

Originally developed for military use, space-based positioning and navigation services have found a growing range of civil applications in recent years. These include assistance to the movement of people and goods in various forms of transport (road, rail, aviation, public transport, maritime), civil protection, management of natural resources (*e.g.* fisheries), development of land infrastructure (*e.g.* energy networks), urban planning and keeping track of moving objects.

As Table 4.6 shows, the demand for positioning and navigation services is expected to be strong under all three scenarios, although the composition of demand may vary somewhat. For instance, military demand is likely to be strongest in scenarios 2 and 3, while commercial demand is higher in scenario 1. More rapid development of urban infrastructure and land transport networks in scenario 1 should create a strong derived demand for space-based positioning services by the construction industry and urban planners. Expected increases in traffic should also generate substantial growth in the demand for navigation and location-based services. The main difference across the scenarios relates to the infrastructure that is eventually put in place, which may be fully interoperable in scenario 1 but very partially or not at all interoperable in scenario 3, with considerable differences in the quality of the positioning and navigation services offered and hence their value for users, notably in urban areas.

Table 4.6. **Summary of expected demand for navigation**

Scenario 1 Smooth sailing	Scenario 2 Back to the future	Scenario 3 Stormy weather
Expected demand: Strong for security, civil and commercial use because of the high level of mobility and the expected large increase in traffic of all kinds. *Implications for space*: Key role for space navigation and widespread use in all forms of transport as well as in financial markets.	*Idem*, although increase in mobility perhaps not as strong.	Somewhat less international mobility than in scenario 2.

Source: OECD.

The increase in the mobility of individuals and goods will be particularly significant and will require a major upgrade of transport infrastructure, notably for air transport, road transport and public transport. Positioning and navigation systems will play a key role for the development of the necessary infrastructure, the management of the growing volume of traffic and the operation of aircraft and vehicles. In particular, the international air traffic management (ATM) system should rely heavily on space-based navigation systems in the next 30 years.

At the same time, the integration of positioning receivers with mobile phones will provide opportunities to create a multitude of consumer-oriented location-based services (LBS) that offer positioning, direction finding, real-time traffic information, etc. The four segments of the current LBS market are:

- Information and navigation services, which provide data directly to end-users, in particular destination location and criteria for journey optimisation.
- Emergency assistance, which gives the location of mobile users in case of distress and need for assistance.
- Tracking services, which provide location data.
- Network-related services, where knowledge of user position improves communication services.

The potential market for LBS applications is enormous (Table 4.7), as it is linked to the expansion of the mobile phone market. Market forecasts indicate that 2.7 billion mobile phones will be in use worldwide in 2020.

Table 4.7. **Potential demand for navigation applications**

	Scenario 1 Smooth sailing	Scenario 2 Back to the future	Scenario 3 Stormy weather
Fleet and traffic management (road, ship, cargo, space)	High	High	High
Air traffic management	High	High	High
Search and rescue	High	High	High
Location-based services	High	High	High

Source: OECD.

Conclusion for navigation

The most promising applications in the next 30 years may be:

- Fleet and traffic management (air, road, ship, space).
- Location based services.
- Search and rescue.

Potential future demand for space transport and manufacturing

Space tourism/adventure

Space tourism, or rather space adventure, is an application that involves taking paying customers to space, on either a suborbital or orbital flight. Suborbital flights involve a short excursion above 100 km. Full-blown space tourism/adventure implies the organisation of longer trips to space, possibly with a limited stay in orbital facilities. It is expected to be attractive to people who are willing and able – despite the expense – to go to extreme lengths to live extraordinary adventures.

According to the World Travel & Tourism Council (WTTC), an international body representing the private sector in all parts of the travel and tourism industry, tourism is one of the world's largest and fastest-growing industries, representing more than 10% of the world's gross domestic product (GDP). In 2003, the tourism sector is expected to generate USD 4 544.2 billion. Over the next ten years, it could grow by 4.6% a year in real terms, *i.e.* to an estimated USD 8 939.7 billion in 2013.

Adventure tourism is an increasingly profitable segment. Trekking in isolated lands, safaris and mountain climbing are being complemented by rides in military jets. For instance, treks to the top of Mount Everest are increasingly popular despite the dangers involved, the costs (licence costs alone reach USD 50 000), and a six-year wait. Space tourism may become the next step in adventure tourism, even if the possibilities are limited at first. This extension of tourism and travel to space is present in all three scenarios, but the demand foreseen differs, as it depends significantly on international tensions, security imperatives and development of space transport.

Various studies of the potential demand for space tourism have been carried out over the years. One study conducted in 2001 for the National Aeronautics and Space Administration (NASA) under the Space Launch Initiative (SLI) concluded that at a price of USD 400 000 a ticket, 10 000 passengers a year would purchase a trip to space, generating an annual USD 4 billion. An SLI-funded study carried out in 2002 suggests that by 2021, the orbital segment might involve 60 passengers a year and yield revenues exceeding USD 300 million. In addition, the suborbital segment might attract as many as 15 000 passengers a year, for revenues in excess of USD 700 million.

An interesting positive sign of the potential of space tourism is provided by the success of Space Adventures, a company that offers tourists visits to Russian space facilities, rides on Russia's parabolic micro-gravity aircraft and trips on a Mig 25 up to an altitude of 80 000 feet. The deluxe package costs USD 12 595 and has attracted almost 1 000 customers. On 18 June 2003, the company announced plans to launch the world's first privately funded mission to the International Space Station (ISS). Space Adventures recently secured a contract with the Russian Aviation & Space Agency (RASA) to fly two explorers to the ISS aboard a new Soyuz TMA "anthropometric" spacecraft. This spacecraft was developed to address issues raised during the US-Russian co-operative programme. "Anthropometric" upgrades remove the limitations on the height of crewmembers on board the Soyuz and therefore make it possible to use it as a "lifeboat" for the ISS.

The logical first step described in all three scenarios is the coming of age of suborbital tourism as an adventure tourism activity (Table 4.8). The customer base tends to decrease across scenarios as the general geopolitical and economical environment deteriorates. Full-blown space tourism in orbit is only considered in scenario 1, as economic conditions improve and civil/commercial use of military technologies accelerates. In this scenario, the advances realised on the commercial side eventually converge with the progress made by the military in developing reusable technologies, leading towards the end of the period to the emergence of a true reusable launch vehicle (RLV). In scenarios 2 and 3, the general environment of distrust and the dual nature of launchers strongly limit space tourism's commercial possibilities.

Table 4.8. **Summary of expected demand for space tourism**

Scenario 1 Smooth sailing	Scenario 2 Back to the future	Scenario 3 Stormy weather
Expected demand: As one of the largest and fastest-growing industries in the world, tourism expands significantly despite concerns about security.	*Expected demand:* Growth of the tourism industry less rapid than in scenario 1.	*Expected demand:* Growth of the tourism industry slower than in scenario 2.
Implications for space: Some tourists attracted by a space adventure if available at a price they can afford.	*Implications for space:* Fewer potential candidates than in scenario 1.	*Implications for space:* Fewer potential candidates than in scenario 2.

Source: OECD.

In all three scenarios, there is a strong drive to reduce the cost of access to space, notably by developing a genuine RLV. In scenario 1 both the military and business entrepreneurs have an incentive to develop such a vehicle. In scenarios 2 and 3, the main driver, at least initially, is the military. As countries co-operate more for civil goals, the development of space tourism is facilitated.

Conclusion for space tourism

Based on social and commercial demand but highly dependent on the development of space transport and security, the following two activities may be promising in the next 30 years:

- Suborbital tourism.
- Orbital space tourism.

Space production activities

In the context of this study, space production includes three types of activities: in-orbit manufacturing (*e.g.* testing and manufacturing of pharmaceutical products and new alloys in microgravity), space power generation (*e.g.* development of space solar power systems to provide energy from space to Earth) and extraterrestrial mining (*e.g.* mines on the Moon).

There have been some in-orbit manufacturing activities over the past decades. They mainly consist of scientific and limited commercial research concerning pharmaceutical products and materials on different space platforms. The demand for larger-scale space manufacturing in microgravity remains largely potential and hypothetical. It may eventually emerge for very high-value items (*e.g.* crystals for semiconductors, new alloys and composites) if the cost of access to space is significantly reduced.

The demand for space power generation is also quite hypothetical, although it is addressed in all three scenarios (Tables 4.9 and 4.10). As Chapter 1 showed, current terrestrial energy supplies should remain sufficient to meet demand over the next three decades. However, there is growing social demand for cleaner energy sources. It is possible to envisage space-generated power systems complementing classical energy sources in time. Theoretically, the economic potential exists, but the ability to produce energy in space and transmit it to users on Earth at a competitive price is far from technically feasible at present. On the other hand, there may be opportunities to use space power satellites to meet the demand for energy consumption in space. Moreover, relay satellites for transporting energy from producers on Earth to consumers on Earth could become feasible over the period.

Mining extraterrestrial bodies (*e.g.* the Moon, asteroids) to provide new resources for Earth or build on-site outposts, is an activity for which potential demand is not well defined. However, in the next 30 years, it may evolve from scientific and exploration missions. There may be future commercial opportunities, but technical and regulatory hurdles are important.

Table 4.9. **Summary of expected demand for space production**

Scenario 1 Smooth sailing	Scenario 2 Back to the future	Scenario 3 Stormy weather
Expected demand: Substantial increase in the demand for goods and energy notably in middle-income countries. Increasing demand for high-technology products in the developed world (*e.g.* new materials, sophisticated electronics, biotechnology products). Likely increase in the demand for clean energy.	*Expected demand:* Same demand patterns but with lower increase than in scenario 1.	*Expected demand:* Same demand patterns but with less increase than in scenario 2.
Implications for space: Attractiveness for some manufacturers of this unique environment. At a competitive price space solar energy would be attractive.	*Implications for space:* Same as in scenario 1 but less promising. Strategic considerations (improve security of supply) may make space solar power more attractive.	*Implications for space:* Same as in scenario 2 but less promising. Strategic considerations (improve security of supply) may make space solar power more attractive.

Source: OECD.

Table 4.10. **Potential demand for space production activities**

	Scenario 1 Smooth sailing	Scenario 2 Back to the future	Scenario 3 Stormy weather
In-orbit manufacturing	Medium	Low	Low
Lunar, asteroid mining	Low	Low	Low
Space power generation	Low	Low	Low
Space relay satellites	Medium	High	Medium

Source: OECD.

The overall development of the space production sector will depend critically on a drastic reduction of the cost of access to space, on the availability of cheap and reliable sources of energy in space as well as on the evolution of space production processes and techniques. It will also depend on the advantage that producing in space may offer over producing on Earth. So far, such an advantage has not been demonstrated.

Conclusion for space production

If some major technical and systemic hurdles are overcome, the following application could be promising in the next 30 years:

- Space relay satellites.

In-orbit servicing

In-orbit servicing includes servicing of space platforms (*e.g.* satellite, space station) for replenishment of consumables and degradables (*e.g.* propellants, batteries, solar array); replacement of failed functionality (*e.g.* payload and bus electronics, mechanical components); and/or enhancement of the mission (*e.g.* software and hardware upgrades). It should also logically include the orderly disposal of satellites at the end of their useful lives, as well as the management of space debris.

Up to now in-orbit servicing has been limited to manned missions (*e.g.* shuttle mission to repair the Hubble telescope) and software upgrades (*e.g.* Galileo mission). The main limitation is cost and the fact that satellites are typically not designed with servicing in mind.

As Table 4.11 illustrates, potential demand for in-orbit servicing and for the disposal of space debris is likely to increase under all scenarios. The ability to service satellites would enable operators to provide more reliable service with less need for expensive back-up satellites and allow them to keep their spacecraft's electronics up to date. The weight and cost of satellites could also be reduced if refuelling is easier and cheaper. The military are likely to be a major driving force behind the development of in-orbit servicing as a way to keep their fleet of expensive satellites in low orbit fully operational. In-orbit servicing could also help to reduce the threat of anti-satellite systems. Moreover, as the orbits that are "homes" to many of today's and tomorrow's space systems are increasingly crowded with space debris, there may be strong strategic, social and commercial demand for the orderly disposal of satellites.

Table 4.11. **Summary of expected demand for in-orbit servicing**

Scenario 1 Smooth sailing	Scenario 2 Back to the future	Scenario 3 Stormy weather
Expected demand: A greater number and longer life expectancy of satellites in operation, increasing need for service including refuelling and electronic upgrades. Space debris of increasing concern and agreement reached on space debris procedures.	*Expected demand:* Same as in scenario 1 but stronger military demand. Agreement on space debris likely because mutually beneficial for all space-faring nations.	*Expected demand:* A little more military demand than scenario 2. International programmes for space debris less co-ordinated.
Implications for space: Possible market for the servicing of satellites, including orderly disposal at the end of their useful lives.	*Implications for space:* Potential market for servicing satellites, including orderly disposal at the end of their useful lives.	*Implications for space:* Potential market for servicing satellites, including orderly disposal at the end of their useful lives.

Source: OECD.

Individual or joint space exploration programmes to the Moon and Mars by different space powers (United States, China, Russia, Japan, Europe) may stimulate the development of some space infrastructure and encourage in-orbit servicing practices. The main limitation relates to the development of service satellites (*e.g.* NextSat) and of an appropriate infrastructure to carry out the servicing.

Conclusion for in-orbit servicing

The following activity might be promising in the long term:

- In-orbit servicing.

Conclusions regarding demand

An analysis of the scenarios developed in Chapter 2 reveals some general demand trends for each major sector of space applications: telecommunications, Earth observation, navigation and potential new sectors (space production, space tourism).

Potential demand reflects social, governmental and commercial imperatives but may be altered by various factors (*e.g.* competition from terrestrial applications). In light of the above discussion, Table 4.12 shows a number of applications that seem to have relatively strong potential demand.

Table 4.12. **Potentially promising applications**

1.	Distance education; telemedicine.
2.	E-commerce.
3.	Entertainment.
4.	Location-based consumer services.
5.	Location-based services: traffic management.
6.	Land use: precision farming.
7.	Land use: urban planning.
8.	Land use: exploration (*e.g.* oil).
9.	Disaster prevention and management.
10.	Environmental applications and meteorology.
11.	Monitoring of the application of treaties, standards and policies.
12.	Space tourism/adventure (suborbital and orbital).
13.	In-orbit servicing.
14.	Power relay satellites.

Source: OECD.

The next section looks at how enabling and space technologies are likely to evolve over the next three decades or so. This will provide an additional basis for assessing which of the above applications should be considered as promising from the perspectives of demand and technical feasibility.

Technological feasibility and opportunities

Whether a particular space application has a chance to flourish depends not only on whether it is likely to be in demand, but also on whether it is already or is expected to be technically feasible and on whether it may be available at a price that will make it attractive to users.

This section carries out a "reality check" on the potentially promising applications identified above. For each, an assessment is made of the likely impact of future progress in "enabling technologies", *i.e.* technologies that are expected to facilitate the implementation of the application and to reduce its cost. Anticipated advances in space technologies are also taken into account. The enabling technologies considered here are nanotechnology, biotechnology, information and communication technologies (ICT), manufacturing technologies as well as robotics and artificial intelligence (AI). No attempt is made to distinguish the individual impact of these technologies. Indeed, it is generally impossible to do so, since technical progress typically results from the combination of several technologies. Microelectromechanical systems (MEMS), for instance, are at the microelectronics-nanotechnology frontier. The space technologies discussed include propulsion technologies, space transport, energy and orbital systems.

Table 4.13 shows the results of the analysis of enabling technologies and Table 4.14 shows those for space technologies. Appendix 4.A1 contains a more detailed discussion of enabling and space technologies.

Implications for the feasibility of promising applications

It follows from the foregoing that many of the applications identified above as "potentially promising" are not only technically feasible today but are likely to become even more attractive in the future, in terms both of their costs and of the services they can provide. This applies essentially to "weightless" information services such as telecommunications, Earth observation and location-based services that will not be significantly affected by changes in the cost of access to space. However, some of these applications, notably telecommunications applications, will face tough competition from terrestrial alternatives.

Table 4.13. **Impact of enabling technologies**

	Application[1]	Impact of enabling technologies[2]
1	Distance education	Distance education will benefit greatly from progress in IT and advances in AI. Particularly significant in this regard will be: • The improved storage/retrieval of information that will allow students to have faster and virtually unlimited access to more teaching material on line. • Better access to broadband. This will give students and teachers more scope for interaction and allow teachers to produce more attractive and informative teaching materials. • Intelligent teaching agents or "virtual teachers" might be able to answer questions in natural language and adjust course content to the student's progress. • Automatic translation could increase student's reach in their search for course-related material.
1	Telemedicine	Like distance education, telemedicine will benefit from progress in IT and AI. It will also be able to take advantage of advances in nanotechnology and biotechnology: • Health smart cards for combined use for health histories, interactive health diagnosis. • Nano-sensors for monitoring patients' health status and nano-actuators for releasing medicine or neural impulses as required. • Automated health kiosques linked to hospitals for telediagnosis. • Interactive home health diagnostic systems. • Telesurgery with paraprofessional assistance.
2	E-commerce	IT and AI applications will enhance the potential use of e-commerce: • Improved storage/retrieval of information should provide consumers with faster access to product information. Shoppers will be able to visit stores virtually in advance of an actual visit. • Virtual consumer agents should facilitate Internet searches and may even be used for transactions. • Broadband will make on-line transactions easier and more effective. • Merchants will have more scope to advertise their products on line and use data mining techniques to better target their offerings. • Merchant virtual agents can learn consumer tastes and adjust their offerings accordingly.
3	Entertainment	Progress in IT and AI will considerably increase the volume and technical quality of electronically delivered entertainment: • More content will be made available to consumers who will have virtually unlimited access to music, video, books. • More interactivity means more potential for sophisticated games and gaming. • High definition will enhance the attractiveness of what is offered. • Virtual agents will help consumers select the entertainment they want.
4	Location-based consumer services	LBS will benefit from progress in nanotechnology, IT and AI: • Receivers will become smaller, lighter and cheaper. • Progress in IT will make systems smaller, more powerful, more user-friendly. The services will take advantage of increased information storage and retrieval capability and greater information processing power to provide the consumer with pertinent information in real time and facilitate mobile-based transactions. • AI will allow the automation of routine tasks and should greatly simplify transactions and information searches.
5	Location-based services: traffic management	Same as above.

Table 4.13. **Impact of enabling technologies** *(cont.)*

	Application[1]	Impact of enabling technologies[2]
6	Land use: precision farming	EO satellite systems will benefit from advances in a broad range of enabling technologies including nanotechnology, IT, AI and robotics: • Nanotechnology will contribute to the development of new materials that are both lighter and stronger. • Embedded nano-sensors may be able to monitor continuously the status of spacecraft. • The increased ability to store and process information will drastically reduce the weight of equipment. • Progress in optoelectronics will greatly increase the capability of space instruments and reduce their weight. • MEMS offer the possibility of developing and operating miniaturised machines. Overall improvement of two to three orders of magnitude in terms of performance/mass may be expected by 2020.
7	Land use: urban planning	Same as above.
8	Land use: exploration	Same as above.
9	Search and rescue	Same as above. In particular: • Positioning chips can be embedded in objects or humans. • Increased information processing and storage capability greatly facilitate decision making (*e.g.* GIS and risk mapping).
9	Disaster prevention and management	Same as above.
10	Environment applications and meteorology	Same as above. In addition, progress in IT will offer opportunities for better modelling the weather and climate change, leading to more accurate forecasts in both fields.
11	Monitoring of the application of treaties, standards and policies	Same as above.
12	Space tourism/ adventure (suborbital and orbital)	Space adventures will take advantage of a broad range of enabling technologies: • Nanotechnology will provide lighter and stronger materials for the spacecraft and the equipment of space tourists. • Embedded sensors and actuators will offer a way to keep track of the health status of space tourists. • With the use of AI, space tourists will be able to train for the mission in a virtual reality environment very close to real space conditions. • AI could also be used to monitor and control important phases in the mission. • Robotic and AI could be used to assemble space hotels.
13	In-orbit servicing	Nanotechnology, IT, AI and robotics will play a key role: • New materials and embedded sensors will facilitate the operation of robots. • Increased information processing and storage capability will greatly facilitate decision making. • Robots will perform autonomously most in-orbit functions (*e.g.* test status of spacecraft, refuel and replace parts as required). • Largely autonomous robots can also perform assembly of large structures such as space platforms, space stations and large antennas, and also dispose of satellites and space debris.

Table 4.13. Impact of enabling technologies *(cont.)*

	Application[1]	Impact of enabling technologies[2]
14	Energy space generation: space relay satellites	Nanotechnology, IT, AI and robotics will play a key role: • New materials can provide the basis for producing cheaper solar panels. • New semiconductors and concentrators may increase the efficiency of solar cells by 30-40%. • Largely autonomous robots (capable of receiving communications, understanding their environment, formulating and executing plans and monitoring their operations) will be used for the assembly of solar power station and deployment of solar panels.

1. The number of the applications (column 1) corresponds to the number assigned to them in Table 4.12.
2. Enabling technologies include here nanotechnology, biotechnology, information technology (IT), robotics and AI.

Source: OECD.

Table 4.14. Impact of space technologies

Applications	Transport systems	Orbital systems
Telecommunications • **Distance education** • **Telemedicine** • **E-commerce** • **Entertainment**	Reduction in launching costs should have limited impact on geostationary Earth orbit (GEO) satellite communication (satcom) systems. However, the quick-around time of RLVs could be a major advantage for launching on short notice a cluster or constellation of satellites in low Earth orbit (LEO), capable of creating an *ad hoc* "infrastructureless" network on the run.	Advances in satellite technology could increase the versatility and attractiveness of space telecommunication solutions when compared to terrestrial competitors: • Onboard processing (OBP) will allow switching, *i.e.* processing packets and routing to destination. The capacity of satellites could increase by a factor of 3-10. • Multi-spot beams offer opportunities for multiple reuse of scarce frequency. Onboard software can be updated and the patterns of spot beams reconfigured. Combining the two technologies would create a peer-to-peer network that connects to several ground stations at once, considerably increasing the availability of bandwidth to users. Improvements in energy generation and storage will reduce the weight and increase the useful life of satellites. More powerful satellites will allow for smaller antennas on the ground, making satellite solutions more attractive to users. Progress in propulsion (*e.g.* ion propulsion, solar thermal rocket engines) will help to increase the expected lifespan of sitcom systems and make them more versatile, *i.e.* better able to respond to changes in demand. New constellations of satellites could benefit from smaller size and better performance, efficient optical inter-satellite links and much improved user terminals. Could this mean a return of the big LEOs? This could have far-reaching implications for the development of wireless telecommunications, notably in countries with limited terrestrial infrastructure.

Table 4.14. Impact of space technologies *(cont.)*

Applications	Transport systems	Orbital systems
Earth observation • **Precision farming** • **Urban planning** • **Meteorology and climate change** • **Natural resource exploration**	The five-fold reduction in the cost of access to space expected over the next 30 years and the ability to deploy a cluster or constellation of satellites more quickly with the development of RLVs should help to increase the attractiveness of EO satellites.	Even more than reduction in launching costs, the expected improvement in the performance/mass ratio by 2-3 orders of magnitude over the period should drive the development of EO satellites, making them attractive to a broader clientele, not only of governments but also municipalities, MNEs, universities, agro-businesses, insurance companies. The increased versatility of satellites should considerably increase their value. It could allow the deployment of specialised systems to focus on specific areas as the need arises (*e.g.* dealing with disasters, natural resource exploration, urban planning).
Location-based services: • **Fleet and traffic management (air, land, sea, space)** • **Consumer services**	Reduction in launching costs should have a limited impact on positioning and navigation systems. The capacity to replenish a constellation quickly could be very important for ensuring continuity of service.	Improved systems sensors (*e.g.* gyroscopes, radar sensors) will increase the accuracy and integrity of positioning signals. The processing of signals will be enhanced (*e.g.* multipath detection and mitigation).
Space tourism/adventure (suborbital and orbital)	The development of space tourism/adventure is highly dependent on the development of an RLV, which depends in turn on progress in propulsion technologies. Possible candidates include: • Advanced rocket engine designs that enable a great number of reuses. • The development of air-breathing engines (*e.g.* scramjets) which accelerate space transport vehicles to Mach 10-15 at an altitude of 60 km. If such developments are successful, civil RLVs may be available by 2020-25. During the period, a four to fivefold reduction in the cost of expendable launch vehicles (ELVs) could also help to lower construction costs for space hotels.	Autonomous robots could be used to construct space hotels to accommodate space tourists. Progress in fuel cell technology could enhance the production of energy and water in space hotels accommodating space tourists.
In-orbit servicing	Suborbital space planes could be used to launch replacement parts by 2010. (e.g. orbital express space operations architecture). RLVs will be used to perform commercial on-orbit servicing by 2025.	Autonomous robots are used for servicing.
Energy space generation: Space relay satellites	Reduction in the cost of access to space is not sufficient for the deployment of a solar power satellite (SPS). However the deployment of space relay satellites and powersats1 is feasible.	Autonomous robots are used to construct space relay satellites and powersats.

1. A power satellite that can be used to provide energy to other satellites.

Source: OECD

The feasibility of space tourism/adventure, in-orbit servicing and power relay satellites over the 30-year period under consideration is more problematic. For each of these applications, the cost of access to space is an important consideration, and the future evolution of costs is a major unknown. It is assumed here, on the basis of expert advice, that costs could decline fivefold by 2030. This seems reasonable, although perhaps ambitious, in light of the rather modest progress achieved over the past 40 years on this front.

In conclusion, the potentially promising applications listed in Table 4.12 can be divided into two groups: *i)* "main contenders", *i.e.* applications that appear to have a reasonable chance to flourish; and *ii)* "outsiders", *i.e.* applications that have less chance of realisation over the period, although demand conditions appear favourable (Table 4.15).

Table 4.15. **Ranking of the feasibility of potentially promising applications**

Main contenders	Outsiders
Distance learning and telemedicine	Adventure space tourism (suborbital then orbital)
E-commerce	In-orbit servicing
Entertainment	Power relay satellites
Location-based consumer services	
Location-based services: traffic management	
Land cover: precision farming	
Land cover: urban planning	
Land cover: exploration (*e.g.* oil)	
Disaster prevention and management	
Meteorology and climate change	
Monitoring of the application of treaties, standards and policies	

Source: OECD.

Summary and conclusion

The three scenarios described in Chapter 2 offer very different visions of possible futures and of the possible evolution of the space sector in the coming decades. On the basis of these scenarios, Chapter 3 provides a list of "promising applications", *i.e.* space applications that are likely to be in high demand over a broad range of future circumstances and that are either already feasible today or have a good chance to become so in the coming years.

In this chapter, the implications of the scenarios for potential demand for space applications for the next decades were examined in greater detail. Potential demand is generally based on social, governmental and commercial needs, but it may be altered by other factors (*e.g.* competition from terrestrial applications). Both traditional and less orthodox applications with strong

potential demand were identified. They include: telecommunications, Earth observation, navigation and potential new sectors such as space/adventure tourism and space manufacturing. Table 4.12 provides a list of the applications selected as "potentially promising" from a demand perspective.

Next, enabling space and non-space technologies were reviewed to assess the likely future evolution of the various components of the space value chain. This gave some insight into the feasibility of the "potentially promising" applications.

As a result, two main categories of promising applications have been defined: the "main contenders" which may develop more rapidly, and "outsiders", which require further technological development (see Table 4.15). Annex 4.A.1 provides more detailed information on the likely evolution of enabling and space technologies over the coming decades.

ANNEX 4.A.1

Enabling technologies and space technologies

Introduction

What will be the impact of new technologies on space activities between the beginning of the 21st century and 2030? These technologies can either be those used directly in space systems (*e.g.* propulsion concepts) or technologies that will influence how space systems are designed, built and operated. The most pervasive of these technologies are likely to be nanotechnology, biotechnology, and information and communications technologies (ICT); other technologies developed for non-space applications, such as artificial intelligence (AI) or computer-integrated manufacturing, will also have an impact on the space industry. Before looking at space technologies as such, it is therefore useful to review issues relating to these more general "enabling" technologies as they might apply to space.

Enabling technologies

Nanotechnology

Nanotechnology will probably have the greatest impact of any of the developments discussed here, but over the next decade, its main contribution is likely to be to research into the atomic structure of molecular objects. This knowledge can then be used to design stronger materials, faster and smaller electronics, and exotic chemicals with unique properties.

If nanosystem devices can then be developed for manufacturing processes, products might include materials that improve reliability and reduce spacecraft weight, resulting in increased payload capacity and higher orbital altitude, thereby ultimately reducing the cost to orbit. They might also include electronic devices that use only a few atoms to store a bit of information, making it possible to drastically reduce the size of on-board equipment such as sensors.

A dense network of distributed embedded sensors could continuously monitor mechanical stresses, temperature gradients, incident radiation, and other parameters to ensure mission safety and optimise system control, thereby resulting in higher mission success rates at lower cost. The outer spacecraft skin could also function as a multi-sensor camera and antenna. If the sensors could be operated as actuators, they could also modify various parameters and eventually enable the development of "smart" outer skins that could automatically repair certain types of damage (*e.g.* from micrometeorites).

In the longer term, nanosystems might be able to exploit *in-situ* resources, *e.g.* from asteroids, to construct and maintain life-support systems, thereby reducing the costs of living in space.

Biotechnology

The space sector can both benefit from and contribute to advances in biotechnology. Research efforts are under way in the in the following domains:

- Regenerative life-support technologies, including air, water and solid waste processing in closed environments.
- Food production in closed environments, including food products generated at the cell level.
- Sensors for space biotechnology applications, including life-support monitoring and monitoring of astronauts' health.
- Molecular microbial ecology of closed space habitation systems.
- Genomics research that supports space agriculture studies.
- Identification of genes, metabolic pathways and other factors that influence seed development and overall food and biomass production in the space environment.
- Solutions for enabling future human space missions, including human health issues in a reduced gravity environment.

Information technologies

Over the next five years, traditional CMOS (complementary metal-oxide semiconductor) silicon-based devices will approach their limits for many applications, and new devices based on innovative architectures and materials that exploit advances in nanotechnology and even biotechnology, will be introduced. Materials might include gallium arsenide (GaAs) as well as organic materials and diamond; chip manufacturing could exploit self-organising and self-assembly, using biomimetic techniques similar to what occurs with DNA or enzymes, to control deposition of materials.

For the longer term, quantum computing is receiving attention because of the quantum effects now being encountered in conventional processors, although quantum devices may prove to be difficult to use in space owing to radiation. In other research, the possibility of using biological material to construct computers is being explored. Researchers have already built "biobots" that mimic the neural networks of simple creatures such as the nematode, which has only 302 neurones (humans have 1 trillion) but is capable of highly sophisticated analysis and adaptation. The hope is to understand the link between electrical activity and behaviour during the first decade of this century.

Whatever the uncertainties surrounding a given development, it is clear that computing power will continue to increase and relative costs to shrink. This will offer opportunities to develop more powerful, more intelligent and more autonomous systems. Implications for the space sector include:

- Increases in processing power will enhance the capacity to process masses of data collected by sensing satellites usefully. Combined with insights derived from biotechnology, it will be possible to develop, among other things, macro-models of environmental processes.
- Increased computer power and data modelling capabilities will significantly increase design and visualisation capabilities for space-based projects.
- Robotics with advanced sensing capabilities will be used for a wide range of space activities, including exploration, maintenance and repair, space-based manufacturing and capture of space debris for recycling.
- Remote sensing, possibly combined with artificial intelligence, will be used to monitor a variety of international treaties.
- Radio frequency identification (RFID) tags will use a hybrid of ground and space systems to provide "smart transport" services, keeping track not only of inventory, but possibly of people as well.

Manufacturing

Before reviewing new technologies, it is worth noting that more mundane measures, such as paperless management, modern inventory control systems, expert systems for checkout and preparation, and collocating manufacturing and launch facilities could provide significant benefits. The Space Transportation Architecture Study (STAS) gives examples of savings that would derive from built-in testing, automated data management systems and low-cost aluminium-lithium expendable cryogenic tanks. Other cost-effective technologies would include improved expendable tanks and structures, automatic software generation and improved flight-management systems.

One of the most interesting technological developments is micro-electromechanical systems (MEMS), *i.e.* using very large-scale integration technology to create structural components. Over the next five to ten years, commercial applications may include:

- Mechanical and inertial devices (mostly micro-sensors for force, pressure, acceleration and flow, and rate gyroscopes).
- Optical devices (displays, optical communication components, laser beam scanners and modulators).
- Devices for data storage.

Longer-term applications may include:

- Full inertial "navigation" on a chip. This would allow an object's position to be tracked in space by measuring all six accelerations it is subject to at all points in time. For example, the gripper of a robot could be tracked. This would allow robots to be much lighter but have the same accuracy, and this would also make them much faster).
- Increasing the speed and/or density of data storage by many orders of magnitude and enabling the read/write mechanisms to disappear into the storage media themselves.
- Optical communication systems, *e.g.* high bandwidth optical switches (micro-mirrors) for multiplexing in fibre-to-the-home or fibre-to-the-curb applications.
- Manufacture of pico- or nano-satellites in low Earth orbit, as opposed to a handful of large satellites in geosynchronous orbit, to serve future telecommunications needs. Large numbers of these satellites could be put into orbit very cost-effectively because of their low mass (tens of kilograms down to hundreds of grams) and because the globe can be spanned with low orbit devices if there are enough of them in orbit.

Robotics and artificial intelligence

Articulated arms and other moving mechanisms to carry out manual work exist, as do cameras and other input devices, but computers do not have the sophistication needed to build a robot with the "learning" and adaptability characteristics of humans. For example, the human retina processes 10 million detections per second or, in computer terms, 1 000 MIPS (million instructions per second). Today's most powerful supercomputer can process 10 million MIPS and IBM is working on a next-generation supercomputer which will perform over 1 billion MIPS by 2005. Moore's law predicts that the upper-end estimate of the human brain's processing power (100 billion MIPS) will be reached before 2020. However, 1 000 MIPS would probably suffice to guide small mobile utility robots through unfamiliar surroundings. By 2010, the first broadly competent "universal robots" could be produced, with 5 000-MIPS "minds" that can be programmed for almost any simple chore. By 2040, freely moving universal robots with humanlike ability to abstract and generalise may be possible.

The most important contributions of robotics and AI to space programmes could be in the development of autonomous, evolvable and highly distributed systems. Autonomy will provide interrelated benefits, including improved mission operations and bolder, unprecedented mission concepts. Space systems could exploit evolvability, *e.g.* by dynamically changing their architecture, structure or function to improve the performance of certain tasks. Evolvability will have a major impact on deployable systems for missions that must provide optimal performance over long periods in unknown, harsh and/or changing environments.

Convergence

The classification employed above is of course somewhat artificial. The most profound changes are likely to arise from the convergence and cross-fertilisation of several of these technologies. For example, computing is likely to benefit from nanoscale manufacturing and biotechnologically inspired design. More powerful computers will in turn facilitate progress in these two fields. But just because a technology is feasible does not mean either that it will be developed or that it will have a major impact on a given domain.

Space technologies

To assess the impact of technology on space, it is important to determine whether space activities are technology-driven or demand-/market-driven. The answer is different for different activities and applications. A very simple segmentation can be proposed:

- Technology-driven activities:
  - Space transport.
  - Manned spaceflight.
  - Science and exploration.
  - Reconnaissance (military).
  - Signal intelligence (military).
  - R&D and demonstration programmes.
- Demand-/market-driven activities:
  - Telecommunications (civil and military).
  - Remote sensing (civil, dual use).
  - Navigation (civil, dual use).

The situation is not, however, as clear-cut as this listing implies. All activities under the "demand-/market-driven" label started in the 1960s, 1970s or 1980s as technology-driven activities, based on technologies at the forefront of scientific and technical advances. This is the case for civil remote sensing, where Landsat (in the United States) and Spot (in Europe) satellites were at the edge of the technical performances of digital sensors. This was also the case for the early Global Positioning System (GPS) satellites, which used for the first time miniaturised atomic clocks in space. Without the availability of some critical technologies, many applications would not have been possible or would not have left the military domain, where cost is much less a factor.

However, current telecommunications satellites are designed with a view to reliability and durability and as little technical uncertainty as possible. Their goal is to provide guaranteed service for 15 years; this generally excludes the use of innovative solutions. Advanced technological developments, which could lead to new applications or considerably improve existing ones, have to be tested and proved reliable in experimental projects supported by space agencies rather than in operational commercial programmes.

Space transport, for its part, is listed as "technology-driven" but this is mainly true during development phases and for specific technologies: rocket engines, structures that determine the performance of the launching systems. A much more conservative approach may be taken for subsystems like electronics, which are subject to a very long qualification process. Once the launcher is operational, any major change in subsystems that could create the risk of failure is avoided. As a result, electronic systems are soon outdated compared to state-of-the-art electronic technologies, so that, after a few years of operation, space launchers are electronic "dinosaurs", for which it may even be difficult to get components.

Space systems are thus paradoxical technological beasts: they rely on technologies at the forefront of progress during their exploratory and development phases, but once they are operational, the focus is on reliability, durability and cost. This situation makes space R&D particularly important as a source of breakthroughs for space activities and applications.

The issue therefore becomes: what technological advances could open the way for major improvements or qualitative changes in space activities during the next three decades? These advances would take place in the "technology-driven" activities and eventually migrate to demand-/market-driven activities. The five main technological sectors in which such advances may be expected are:

- Space propulsion.
- Space transport systems.
- Energy generation.

- Orbital systems (platforms, payloads and instrumentation).
- Manned spacecraft.

Space propulsion

Space propulsion is by definition the enabling technology for going to space and manoeuvring there, around the Earth or much further, including orbiting distant celestial bodies, landing on some of them and possibly travelling back to Earth. This technical field can be segmented in three domains:

- Main propulsion, for the first stages of transport systems, characterised by high thrust and short working time (minutes to tens of minutes at most).
- Injection and space manoeuvring propulsion, characterised by lower thrust, ability to restart many times and a longer duration of work (from tens of minutes to many days).
- Exotic propulsion systems.

Main propulsion

Main propulsion is currently limited to rocket engines using liquid propellants or solid (powder) propellants. Although the first satellite was orbited 46 years ago, the high-thrust rocket engines required by space transport systems are still critical parts, expensive to develop and manufacture, and inherently unreliable. Catastrophic launch failures are still the fate of many space missions, with reliability of the best operational launchers in 2003 in the range of 95-98%. This is clearly a domain where the issue is not a technical breakthrough but gradual improvements of:

- Reliability, which means larger technical margins, better reliability analysis tools, improved industrial processes.
- Cost, which is also linked to improved industrial processes.

With this priority in mind, one can consider significant improvements in terms of:

- Duration of work, leading progressively to the possibility to recover and reuse engines or whole transport systems.
- Ecological acceptability, which may mean going from solid boosters (Ariane-5, space shuttle) to liquid boosters using safer propellants (methane/liquid oxygen; liquid oxygen/liquid hydrogen).

It is likely that progress in main rocket engines will be mostly incremental and focused on the industrial process until the end of the 2010s, with the disappearance of solid boosters and experimental recovery and reuse

of first-stage engines. Radical innovations will remain at the level of R&D and demonstration, with:

- Advanced rocket engine design enabling a great number of reuses.
- Development of air-breathing engines, such as supersonic combustion ramjets (scramjets), which could theoretically accelerate a space transport vehicle to Mach-10-15, at an altitude of more than 60 km.

Both technologies will be directed towards the creation of reusable launch vehicles (RLVs), but it is not possible to forecast which will prevail. Rocket engines are simpler but air-breathing engines offer theoretically better performance. Such reusable engines will be incorporated in the RLVs that are expected to appear from 2015 for military applications and from 2020-25 for civil space transport.

No technical breakthrough will be needed to build the larger launchers, with payloads much higher than Ariane-5 or the shuttle (about 20 tons in low Earth orbit – LEO), that may be required for manned spaceflights to the Moon and later to Mars. Very high-thrust engines like the Russian RD-171 may be sufficient for this task, particularly once reliability increases significantly and cost decreases owing to intensive use by commercial launchers (Zenit, Atlas-5).

Injection and manoeuvring engines

Upper stages and manoeuvring stages propulsion, used to deliver payloads in various orbits and to change the trajectory of lunar or planetary probes, rely on mature and safe liquid propellant rocket technologies. Major improvements can be only expected for lunar and planetary probes or spaceships, with:

- Use of solar energy, instead of chemical energy from bi-propellant rocket engines, to heat a propellant. Solar thermal rocket engines can be used to manoeuvre or travel from LEO up to geostationary Earth orbit (GEO), the Moon or interplanetary space as long as the craft does not travel too far from the Sun.
- Electric rocket engines, which convert electric energy from a solar or nuclear generator into kinetic energy of charged particles or neutral plasma accelerated by electromagnetic fields. They provide smaller thrusts but for a long duration and can provide very large changes in speed and trajectory economically.

The most promising technology is electric propulsion, which has begun to be used routinely, on a small scale, on telecommunications satellites and experimental spacecraft like the European Space Agency's (ESA) Smart-1 lunar probe. Electric propulsion at a much higher scale (higher thrust, better performance, very long duration) will be mandatory for the future of the exploration of the solar system. The R&D must have very high priority, but applications will depend on the availability of powerful nuclear energy sources (see below).

Exotic propulsion systems

There is no lack of ideas on exotic propulsion systems, which could, in principle, revolutionise space transport during the next decades. The following list is not exhaustive:

- ***Laser propulsion:*** A laser beam from the Earth's surface or a space station heats a distant rocket engine, which ejects hydrogen or another propellant at very high speed.
- ***Electromagnetic gun:*** A conducting container is accelerated by electromagnetic forces at very high speeds (many km/s) and ejects (at the top of a mountain, in space, at the surface of the Moon) a payload which could be an inert mass (exploitation of extraterrestrial resources for space workshops or colonies), the upper stage of a rocket or a spacecraft.
- ***Space tethers:*** Payloads are attached to long cables which are deployed from space stations to take advantage of the law of the conservation of momentum to increase the energy of the payload and take it to higher orbits without any consumption of propellant.
- ***Space sails:*** Using solar energy pressure on a light-reflecting structure to accelerate the structure (a variant uses the pressure from a laser beam).
- ***Fusion propulsion:*** Two versions: a fusion nuclear reactor provides energy for very high-thrust electric propulsion; micro thermonuclear explosions created by laser fusion technologies eject the fusion products at extremely high speeds.
- ***Antimatter propulsion:*** Annihilation of matter and antimatter as an energy source for rocket operation.
- ***Space elevators:*** Erecting a 100 000 km beam with one extremity close to the Earth's surface and its centre of gravity on GEO; the law of the conservation of momentum would make an object climb freely along the beam up to 100 000 km (the object's increased energy comes from the rotational energy of the Earth, which is slightly decreased).

There is no intractable technical reason why the first four of these technologies cannot be applied before 2030. For each, the question is, as usual for exotic technologies, what would be the driver for effectively developing the technology? The most promising scheme may be the electromagnetic gun, which may rely on military R&D (for kinetic weapons on Earth or in space) and may prove very useful on the Moon, once a permanent base is established on the lunar surface.

The last three technologies raise fundamental scientific or technical issues. Fusion reactors are not expected to be available before 2030 and antimatter energy generation cannot be considered before well into the second half of the century, if not the following one. The space elevator concept is very simple, and would not require a fundamental scientific breakthrough. Its implementation would depend, however, on developing a material whose strength is an order of magnitude greater than that of a diamond.

Space transport systems

Space transport systems must be divided between unmanned one-way systems and two-way reusable manned or unmanned systems. Their requirements and constraints are very different and point toward different technological solutions. With the hindsight of experience, the US space shuttle has shown that it was an error to design a system to address both kinds of demands.

Unmanned one-way systems

Conventional expendable launch vehicles (ELV), like Europe's Ariane-5, the United States' Delta-4 and Atlas-5, Russian's Proton and Soyuz, Ukraine's Zenit, Japan's H2A, India's PSLV and GSLV and China's Long March, will remain the main workhorses for unmanned space transport during the coming two decades. It is even safe to forecast that no new major expendable heavy launcher will appear, with the possible exception of Russia's Angara. Past records show that the lifetime of the expendable launcher can be very long (more than 40 years for the Russian Soyuz and the American Delta-2).

One can argue that gradual evolution is a better way to improve conventional rockets than a shift to a totally new launcher. The situation is comparable to that of high-thrust rocket engines: the goal will be better reliability and cost, with a focus on the industrial process. This does not mean that very significant progress will not be made, since there is much room for improvement. For the main market economies' expendable launchers one can expect:

- An increase of reliability to better than 98% by 2010 and better than 99.5% by 2020.
- A decrease in cost (USD/kg in LEO) by at least a factor of three by 2010 and of five by 2020.

This will make the emergence of competitive RLVs for one-way unmanned transport more difficult. Therefore, large expendable conventional launchers will still exist in 2030 and maybe later. This is not, however, a real issue since:

- They will be very reliable and economical by that time.

- New, very heavy expendable launchers of the Saturn-5 or Energia class may be needed around 2020-30 for manned lunar and later for Mars missions.
- RLVs will be developed in the 2010s and 2020s for specific missions for which expendable systems are inadequate.

Two-way unmanned and manned transport systems

These systems are defined as those able to travel to space on suborbital or orbital trajectories and return with at least a partial payload. They can be classified as:

- Non-reusable recoverable orbital systems.
- Reusable (partly or totally) recoverable orbital systems.
- Suborbital reusable systems.

Non-reusable recoverable orbital systems. Manned and unmanned recoverable spacecraft belong to this class, which has included in the past military reconnaissance satellites (particularly in the Soviet Union) and manned spaceships (Vostok, Voskhod and Soyuz in URSS/Russia; Mercury, Gemini and Apollo in the United States). The new manned Chinese spacecraft, which uses a conventional ELV to reach orbit and has a recoverable capsule for returning to Earth with a payload (images, crew), is also of this type.

This type of system was expected to disappear, at least for manned missions, with the establishment of the space shuttle. However the shuttle's problems have given a new lease on life to manned capsules; since the Columbia accident in January 2003, the crew of the International Space Station (ISS) is being transported exclusively by the Russian Soyuz until the shuttle is again operative, in principle sometime in 2004. This situation should prevail during the present decade and probably the 2010s. One can expect:

- Soyuz to remain in service until 2010.
- NASA to develop and operate from 2010 a recoverable spacecraft, called the orbital space plane (OSP), the recoverable part of which could take the shape of a ballistic re-entry capsule and could be launched by a conventional ELV such as Atlas 5 or Delta-4.
- The Chinese space programme to make use of its Shenzhou recoverable spacecraft well into the 2010s.

This category of transport system will:

- Benefit fully from the greater reliability and lower cost of expendable launchers.
- Provide the technical basis for large spacecraft to land on Mars from the 2020s, including manned missions.

Reusable (partly or totally) recoverable orbital systems. The space shuttle is the only active system in this class since the only other one developed, the Soviet Buran, flew only once in the 1980s. Prior to its first flight in 1981, the development of the space shuttle raised unrealistic hopes of an inexpensive (less than USD 50 million per flight with a crew of seven and a payload of 30 tons in LEO) and reliable spacecraft (chance of catastrophic failure smaller than 0.0001), with a short turnaround cycle (50 flights a year with a fleet of four orbiters). The differences between expectations and reality are overwhelming:

- Only about 120 flights in 22 years.
- Two major accidents killing 14 and destroying two orbiters.
- A price tag of about USD 350 million per flight.

The United States cannot scuttle the space shuttle because it is indispensable for final assembly of the International Space Station. However, it is clear that the shuttle must fly rarely (two to three times a year), only for critical missions, and be supplemented by the OSP, a much smaller and less capable spacecraft from the previous generation of manned transport systems (see above) but representing far less risk. Barring another shuttle accident, the combination shuttle/OSP may provide the basic transport service for the ISS until at least 2020 and maybe 2030.

The lesson of the shuttle is that developing an RLV will take longer and be more difficult than earlier believed. The inability of many experimental programmes, mostly American (Orient-Express, X-33), to reach their goal is further proof of the difficulty involved. Therefore, a tentative schedule for RLV development may be:

- 2003-15: intensive R&D, particularly in the United States with military funding, focused on advanced reusable propulsion and reusable hot structures, with *ad hoc* demonstrators.
- 2015-20: military hypersonic cruise vehicle, reaching Mach-12/15 to operate as hypersonic bombers with global reach and as the first stage of military space launchers with high reactivity and short turnaround for conducting special missions (inspection of satellites, recovery of satellites, etc.).
- 2020-30: co-existence of TSTO (two stages to orbit) civil RLV based on military space-plane technologies to conduct specific missions (transport to and from space stations, preparation of lunar manned spacecraft and later Mars spacecraft in LEO, etc.) and of more economical ELV for providing most conventional commercial space transport.

By 2030, the RLV may become competitive with the ELV for conventional space transport (one-way transport of application satellites) and that the transition from ELV to RLV for all space transport may begin, but it will not be completed before 2040 or 2050. Industrial experience in other domains shows that the replacement of one dominant technology (*e.g.* energy from coal) by another (*e.g.* oil, gas) is always a lengthy process.

This will create real challenges for Europe, Russia and Japan, and maybe China and India, because the necessary investments in R&D, and later in systems, will be huge, and the technology difficult to master. With the possible exception of the United States, and perhaps even for the United States, the challenge may be so great that a multinational effort, of the kind existing for instance for nuclear fusion research, might be mandatory. For instance, a pooling of resources between Europe, Russia and Japan could be considered.

Suborbital reusable systems. The development of real space tourism, *i.e.* space travel for (nearly) everybody, cannot seriously be contemplated in the absence of recoverable spacecraft (even if a few tourism flights take place aboard Soyuz spacecraft during the current decade, at a price of USD 20 million) or RLV, which will appear late and be very costly well into the 2020s. It seems more likely that space tourism will develop along a different technical path, starting with relatively low-speed (Mach-4) suborbital flights. The suborbital space planes developed for this application, in the spirit of the X prize competition (which calls for launching a manned craft able to carry three people to 62 miles and returning it safely to Earth twice within 14 days), will require significant progress in:

- Reusable liquid rocket engines.
- Structures able to sustain the thermal and mechanical strains of a steep atmospheric re-entry at Mach 4.
- Rocket systems with a short turnaround.

These technical challenges are much more tractable than the RLV's propulsion and re-entry problems and it may be possible to use technologies from the aviation world. If commercial success follows progressive technical mastery of suborbital flights, one may expect the initialisation of a virtuous circle, with:

- More activities and accumulation of experience.
- Development of systems that fly faster and higher.

Along this virtuous circle the systems developed and operated for space tourism may converge with orbital space planes and RLV systems by 2030 and add into the operation of commercial RLV the experience accumulated with tourism to develop orbital space tourism.

Energy generation

Energy is absolutely crucial for space systems, which currently rely on three kinds of sources:

- Photovoltaic solar generators, which convert sunlight directly into electricity, with an efficiency of about 20%. The largest solar generators provide less than 100 kW of power.
- Electrical storage devices, used when solar panels are not illuminated (*e.g.* when the sun is eclipsed by the Earth) or for highly manoeuvrable spacecraft for which large solar panels would be inconvenient (*e.g.* the shuttle). Most satellites use electrochemical batteries (like nickel hydrogen batteries). The shuttle uses H_2/O_2 fuel cells, which simultaneously provide a significant amount of power (about 12 kW for two weeks) and water for the life-support system. Lithium-carbon batteries may provide a much bigger improvement in performance than that achieved with the switch from nickel-cadmium to nickel-hydrogen batteries.
- Nuclear energy generators, currently used only for interplanetary space probes that are to travel far from the sun (exploration of outer planets) or operate at the surface of planetary bodies, like the Moon and Mars, where solar energy is limited, inconvenient or unavailable for long period of time (two successive weeks on the Moon). All nuclear generators in service at the moment are radio-isotopic generators, which make use of heat from the radioactive decay of radioactive isotopes to warm a spacecraft and convert part of this heat to electricity.

Other energy sources include:

- Space fuel cells are one order of magnitude more costly than photovoltaic solar generators and can be used only for short missions.
- Dynamic systems using solar power to heat the fluid of a heat engine have a higher thermal efficiency and can be used for higher power levels than photovoltaic systems. However, photovoltaic has a cost advantage for power requirements below 20 kW, while nuclear systems would be more advantageous above 100 kW.

Considering the future of energy generation in space, the following points are addressed:

- Prospects for solar panels and electrical storage in space.
- Nuclear energy generators.
- Space energy resources for the Earth or space habitats.

Prospects for solar panels and electrical storage

Only incremental progress may be expected for these mature technologies, which were developed from the beginning for space applications, with reliability as the major driver. Space solar energy is extremely expensive, with a cost of the order of USD 1 million/kW of peak installed power. With the need for more power, silicon will need to be replaced by a higher-efficiency semiconductor, with gallium arsenide the most likely substitute. GaAs is 40% more efficient than silicon, more resistant to radiation, and has a temperature degradation rate half that of silicon. Although GaAs cells cost almost ten times more than silicon cells, this could be offset by lower launch costs owing to weight savings. Indium phosphate ($In_3P_2O_8$) is similar to GaAs in efficiency but is more resistant to radiation degradation; however, practical applications seem further off.

Even if solar cell efficiency increases by some 30-40% with the use of new semiconductors and concentrators during the next decades and manufacturing costs decrease significantly, space solar energy will remain very expensive, at over USD 100 000/kW. To improve this situation, the following approach may deserve consideration: the transformation of space generators into autonomous systems, developed by energy utilities, which would lease the generators to users. This concept, "powersat", would provide electricity to the satellite or space station by physical links or wireless transmission. The approach would be viable only if the demand for energy in space reaches the point at which it is in the interest of satellite and station manufacturers to outsource energy generation (large numbers of powerful satellites, new power-hungry applications in space stations).

Nuclear energy

Nuclear energy is one of the most critical technologies for the future of space activities. It is the key for:

- Efficient and shorter trajectories to the planets: electric rocket engines will require large amounts of power to provide enough thrust to propel large unmanned spacecraft and later manned spacecraft towards Mars and maybe other distant celestial bodies. Transit time of three months from Earth to Mars rather than the typical seven months for optimal trajectories with chemical propulsion would be conceivable. The level of power required will be in the range of 100 kW to tens of MW, which can only be delivered by nuclear fission reactors. These will have to be compact and safe. Launching the reactors from the Earth's surface will not be an issue, since the reactor can be launched before divergence of its core, when there is very little radioactivity aboard (enriched uranium is only slightly radioactive). Some issues will of course have to be resolved for safe operation in space:

radiation protection of the spacecraft and its crew, if there is one; disposing safely of the nuclear reactor at the end of its mission.

- Powerful sources of energy on the surface of the Moon and Mars, or other celestial bodies, for fixed or mobile research stations (unmanned and later manned), enabling the use of extraterrestrial resources to extract oxygen, water and other elements, molecules and material from the environment.

The development and exploitation of space nuclear reactors will be indispensable to any serious plan to explore the solar system.

For the foreseeable future, nuclear power is likely to be limited to scientific missions such as planetary or deep space exploration where solar or other technologies are impractical. At present, most attention is focused on small systems, around 100 kW, but in the longer term nuclear fission reactors coupled with magneto-hydrodynamic (MHD) generators could serve as suitable power plants of low specific mass for high-power electric propulsion systems. These systems display the necessary energy density requirements while remaining entirely within the realm of current engineering feasibility. According to NASA, the technological development risk for multi-megawatt installations is only slightly greater than for turbogenerator-based power plants, yet the potential payoff is immense, a decrease of an order of magnitude or more in system-specific mass.

Space energy resources for the Earth or space habitats

The original idea to collect solar energy in space and transmit it to Earth via microwave beams dates back to 1968 and a famous article by Peter Glaser in *Science*. The concept is brilliant, and possibly more so today, when much attention is devoted to the emission of greenhouse gases (GHG) by energy stations. A solar power satellite (SPS) would provide electricity to terrestrial grids with an absolute minimum of GHG rejection and heat load for the environment. However, the economic feasibility of the SPS concept is still very remote, owing to the cost of space transport (still more than USD 1 000/kg in GEO by 2030) for very heavy systems (at least 1 000 tons in GEO for 1 GW of power) and of solar panels. SPS is an energy option for the second half of the 21st century, the same timeframe as for fusion energy. However, preliminary research will have to be conducted during the next decades:

- To update the concept, taking into account technical progress in solar cells, materials, etc.
- To test wireless transmission of energy, which could be also useful for powersats.

Another, less ambitious scheme may be worth considering: the use of wireless transmission of energy to transport huge amounts of electricity between remote regions where cheap energy resources may be available (northern Canada, Siberia) and consumption regions thousands of kilometres away. The microwave beam would be reflected by a GEO meshed reflector, with a mass of a few tens of tons only. Such an energy relay satellite (ERS) may make sense, if not by 2030, then during the two following decades.

Orbital systems

Propulsion and energy generation are considered separately from orbital systems (satellites, space probes, orbital stations), of which they are an integral part, because their progress relies mostly on applied physics, where advances are relatively slow, with major changes taking years if not decades. Many other parts of orbital systems depend more on kinds of technology that currently advance much more rapidly: microelectronics and information processing, optics and optoelectronics, MEMS (part of nanotechnology) and materials.

- ***Microelectronics:*** If "Moore's law" remains valid in future, integrated circuits will have processing capabilities 1 000 times more powerful by 2018 (*i.e.* the middle of the period under consideration) than in 2003. Even if space systems integrate new electronic hardware and software conservatively, this will have a tremendous impact on space platforms and their payloads.
- ***Optoelectronics:*** A related field with extremely rapid progress. Associated with advances in optical systems, *e.g.* the development of adaptive optics, it will greatly increase the capabilities of space instruments while making them much lighter.
- ***MEMS:*** These systems extend the miniaturisation and integration concepts that are at the core of the success of microelectronics to micro-mechanisms, enabling the development and operation of robust miniaturised machines that could revolutionise space exploration.
- ***New materials:*** New materials, strong and lightweight, metallic or composite, some taking advantage of developments in nanotechnology (nanotubes for instance), will be used.

It is impossible to address all the changes that will follow the evolution of these technologies. The following is a look at some major trends.

Miniaturisation of information collection satellites and probes

Earth observation satellites and scientific satellites and probes, which collect and process information and are not constrained by a physical parameter (radiated power) like telecommunication satellites, will decrease in weight while gaining in performance. In two decades, an order of magnitude has already been gained in terms of mass and performance: Spot-1 had a mass of 2 tons and a resolution of 10 meters in 1986; Pleiade will weigh 200 kg and have a resolution of less than 1 meter in 2008, an improvement in performance of more than a factor of 100 by unit of mass. The same trend

exists in space exploration, with the ESA Mars Express probe of 2003 more capable than the US Viking probes of 1976, which weighed 20 times more. This trend can be expected to continue, with an improvement of two or three orders of magnitude by 2020 in terms of performance/mass.

Telecommunication satellites as routers

Current telecommunication satellites are mostly designed as very simple relays, using so-called "bent pipes transponders", which retransmit the signals they receive with a minimum of processing, thereby placing most of the complexity of the telecommunication process in the ground segment. This makes sense since it is possible to modernise the ground segment to take technical progress into account, whereas the satellite in space cannot be modernised during its lifetime of 12-15 years.

This is about to change with the introduction of onboard processing (OBP), a technology already available on some military satellites. It uses an "intelligent" payload which is able to process the flow of digital packets that constitute a telecommunication signal and to address each packet as requested to a specific beam and destination. This points the way towards more complex satellites with multiple spot beams. They would be able to operate as "routers in the sky" and become nodes in the global telecommunication network, enabling multiple reuse of scarce frequency resources. They could provide broadband services in places where other broadband technologies are unavailable. Even if physical changes cannot be made during the lifetime of the satellite, the on-board software can be easily updated and the pattern of spot beams reconfigured.

An accompanying trend will be the emergence of high-performance, low-cost, fully "plug-and-play" user terminals using flat array antennas. The lack of such advanced user equipment explains the late deployment of multimedia satellites using OBP like Spaceway or Skybridge at the beginning of the 2000s.

The return of the satellite constellation

During the last few years, a first generation of satellite constellations providing global telephony services (Iridium, Globalstar) were commercial failures. However, these failures were mainly due to poor understanding of the telecommunications market and the basic physical advantages of constellations. Global networks of LEO or MEO (medium Earth orbit) satellites will lead to a resurrection of the concept, both for telecommunications and remote sensing. New constellations will plainly benefit from:

- Smaller size and better satellite performance.
- Efficient optical inter-satellite links.
- Much improved user terminals.

Smart robot explorers

In-situ exploration of celestial bodies will take full advantage of:

- Small robot size, enabling multiplication of probes, and improving geographical coverage.
- Huge onboard computing capabilities providing greatly increased autonomous control, including some AI applications.
- MEMS, providing greater mobility and accessibility to difficult places, including digging holes, climbing rocks, etc.
- Miniaturised laboratories able to conduct sophisticated physical, chemical and biological analysis.

Summary and conclusion

The review of enabling and space technologies presented in this annex provides some clues to the likely future evolution of the various components of the space value chain.

- ***Telecommunications:*** Space telecommunications should be able to take advantage of progress in enabling technologies (micro-electronics and communication technologies) to maintain and perhaps increase its market share. Particularly significant will be:
  - Packet switching in orbit, the use of spot beam and frequency reuse.
  - The return of constellations.
- ***Earth observation:*** Advances will continue in the miniaturisation and increased capability of satellites. Improvements of two or three orders of magnitude are expected.
- ***Positioning and navigation:*** With the advent of Galileo and GPS, further progress will be achieved in the precision and reliability of positioning and navigation services, paving the way for a greater range of applications as the cost of receivers declines.
- ***Transport services:*** Progress is likely to be more evolutionary than revolutionary:
  - ELVs will become more reliable and their cost may drop five-fold over the next 30 years.
  - RLVs will come gradually on stream, first as a hypersonic bomber by 2015.
  - Suborbital space tourism/adventure could develop over the next decade or so and evolve gradually to orbital space tourism over the next couple of decades, thus contributing to the development of commercial RLVs towards the end of the period.

- ***Space power and space manufacturing:*** Because reduction in the cost of access to space is expected to remain relatively modest over the next 30 years, little progress is expected on this front:
  - Progress could be achieved in power generation and transmission (space-to-space solar power relay satellites could become available towards the end of the period).
  - Progress in AI and robotics will greatly facilitate the construction of large structures in space.

Final remarks

The space sector is currently recovering from the downturn of the early 2000s, but it is likely to face further periods of reduced activity in future because of the cyclical nature of the industry and the chronic situation of oversupply that plagues the upstream segment.

This characteristic of the space sector will have important consequences for space firms and the future structure of the space industry. The firms most likely to weather sharp declines in demand in the coming years will be those able to draw customers from all three space sub-sectors (commercial as well as civil and military), since civil and military space are less sensitive to overall economic conditions than commercial space. It would help space firms to be integrated into larger entities with other lines of business more immune to business cycles, particularly if such entities have sufficient financial resources to withstand adverse market conditions in the medium term. However, such integration makes sense only if there is significant synergy between space activities and the other lines of business. Vertical integration may also be a possibility in some cases since the industry's downstream segment seems to capture most of the value generated in the value chain and is less affected by business cycles. However, space actors may not have the expertise to develop downstream applications successfully and space is often a small element in the operation of downstream firms. Moreover, space firms may not wish to put themselves in the awkward position of having to compete with their customers.

Despite these short- and medium-term problems facing some space firms, the longer-term future of the sector as a whole appears to be bright over a broad range of possible futures, as the scenario-based analysis of Chapters 2 to 4 illustrates. Notably, future space developments are likely to be largely driven by strategic considerations that reflect heightened concern about security at home and abroad. Moreover, the range of civil applications is also bound to increase, since the value of space as a tool for solving social problems should be increasingly recognised, while commercial applications may flourish in a favourable international business climate.

In the short to medium term, weightless information applications, including telecommunications, Earth observation and navigation applications, are likely

to dominate in light of the high cost of access to space. In the longer term, transport and manufacturing applications (*e.g.* space tourism, space power relay satellites) may come on stream if and when the cost of access to space declines and space travel becomes more reliable.

While a number of space applications appear promising, their future development is far from assured. Factors that will have a major bearing on their development include the framework conditions that determine the overall business environment faced by space entrepreneurs, as well as factors more directly related to the business model adopted for developing the applications. The framework conditions are considered in Phase 4 of the project; business models are addressed in Phase 3. Consideration of the latter typically requires answers to a number of questions, notably:

- What is the nature of the value created for the user by the offerings based on the technology?
- Who are the potential users and how will they use the offerings?
- How are the offerings to be produced and delivered to users?
- What is the cost structure and profit potential of the proposed scheme?
- How will the firms that exploit the technology be positioned between suppliers and customers in the value chain, including identification of complementors and competitors?
- What strategies will be used to establish and maintain competitive advantage *vis-à-vis* rival technologies?

The formulation of successful business models for the space sector is particularly challenging. One reason is that space business ventures typically involve large capital investments, long payback periods and high risks. The level of risks is considerable not only on the supply side (will the offerings derived from the technology be produced on target and meet expectations?) but also on the demand side (will the market for the proposed offerings materialise? will such offerings still be superior to alternatives when they reach the market?).

The fact that the upstream space segment is typically very small when compared to the downstream segment is another complicating factor, although it is an essential link in the value chain that it helps to generate. This means that the decision makers who make the critical technological choices upstream may not be in a position to fully understand the downstream implications of their decisions, or they may have little incentive to pay much attention to such implications, if the downstream benefits accrue to others.

Keeping all of this in mind, it will be important to assess in Phase 3 of the project the actions that governments may wish to take to reduce the impediments to private investment and make such investments more attractive to private investors. These could include measures to: *i)* reduce private investment requirements; *ii)* increase expected private-sector returns on investment; *iii)* reduce private-sector perceived risk; and *iv)* create new business opportunities. In some cases, the applications under consideration may not generate much in terms of direct revenues but could nevertheless have substantial and broadly diffused indirect or downstream benefits. This may call for more direct public involvement in the development of such applications or/and of related new public space infrastructures.

ANNEX A

*Measuring the space economy**

Scope of the annex

This annex brings together official and unofficial estimates of the space sector and its impact on economic activity. It draws mainly on OECD databases and indicators developed by the Directorate for Science, Technology and Industry and the Statistics Directorate. It also includes data from private sources, such as industry associations. It highlights some of the main problems involved in deriving internationally comparable data for this industry. The indicators cover:

- The contribution of the *space sector to OECD economies*: value added and revenues of the space sector; the size and growth of its different segments, *e.g.* manufacturing of space equipment, satellite services, etc.
- *Trade in space equipment*: the role of exports of space equipment; growth over time; the main destinations of exports.
- *Research and development directed at space*: public budgets for space-oriented R&D; private spending on R&D in the aerospace sector.
- *Innovation*: patents in space-related technologies.
- *Public budgets for the space sector*: the main governments involved; their civil and military budgets; the size of the budgets relative to GDP; the increase in budgets over time.

This annex serves as a first compilation of statistics on the space economy and could be the first step towards developing a set of official and comparable statistics on the space sector and its contribution to economic activity. Owing to the novelty of the data and indicators presented, country comparisons should be interpreted with caution.

* The annex was prepared by Dirk Pilat and Sandrine Kergroach-Connan of the Economic Analysis and Statistics (EAS) Division of the Directorate for Science, Technology and Industry (DSTI). Data collection was finalised in March 2003.

Conclusions and recommendations

The present annex reveals the somewhat fragmented nature of statistics on the space industry. Official statistics often lack detail and comprehensiveness. Most of the industrial classifications used by statistical offices provide no breakdown for this industry, although the US North American Industry Classification System (NAICS) is a partial exception. Although product and trade classifications provide more detail, they only cover goods produced and traded. They do not cover the services that are associated with the space industry. R&D and patent data also provide some information but only on specific characteristics of the industry.

Data from private sources provide greater detail and are more comprehensive but raise questions with respect to their international comparability and comparability across sources. Their definitions of the industry differ considerably, and private compilers do not always use standard statistical conventions. Nonetheless, information on the space sector is readily available from a wide range of sources, mainly because it is not very difficult to define activities linked to the space industry, and also because many firms in the space sector are quite large and organised in industry associations. The substantial amounts of private data available offer a relatively comprehensive view of many segments of the industry.

Despite the relative richness of private data, these sources must be closely scrutinised in terms of their use of accepted statistical conventions and procedures, consistency over time and solidity of documentation. Policy makers should in any case be cautious in using private estimates or industry projections of demand to guide policy decisions, as private data do not follow the same statistical guidelines as official sources. Consideration might be given to developing a set of "official" space-sector statistics, which could draw on private data and available official sources. The following recommendations may help to improve the quality and quantity of official statistics on the space industry:

- Consideration should be given to establishing a comprehensive inventory of the available statistics on the space industry from private and public sources. Careful review and comparison of the available estimates, as well as of the underlying methods and data sources, could improve international comparability. Working with private data providers to improve their estimates, including their consistency over time, and to increase awareness of internationally agreed statistical conventions may also be useful.
- Work could be undertaken to reach agreement on a working definition (or definitions) of the space industry, *i.e.* what it covers and what should be included in statistics.

- It would be helpful to examine whether changes in industrial classifications are needed to better capture the industry. Given the deadlines for the 2007 revision of the United Nations International Standard Industrial Classification (ISIC), it may be a long time before suggested changes in industrial classifications can be integrated in international standards. National classifications, such as NAICS, already cover certain parts of the space industry and may be easier to change, in particular if the changes are relatively minor.

Official statistics on the space sector Available indicators

1. Size and growth of the aerospace sector

- The space sector is not well captured in official structural statistics. However, a first glance at official statistics on the aerospace industry shows that it is relatively small. It accounts for less than 4% of total manufacturing value added in all G7 countries and less than 0.6% of economy-wide value added. However, it has grown relatively rapidly.
- The United States, France, the United Kingdom and Germany account for the bulk of the aerospace industry in OECD countries.
- In most countries, the manufacturing of space equipment accounts for only a small part of the aerospace industry. It is thus likely to account for only a small part of overall manufacturing value added in OECD countries.

The space sector in official statistics

Statistical terminology does not currently offer an internationally agreed definition of the space industry. In broad terms, the space sector can be defined as including all public and private actors involved in providing space-enabled products and services. It therefore comprises a long value-added chain, starting with the manufacturers of space hardware (*e.g.* launch vehicles, satellites, ground stations) and ending with the providers of space-enabled products (*e.g.* Global Positioning System [GPS]-based navigation systems) and services (*e.g.* satellite-based meteorological services or direct-to-home video services) to final users.

The main problem in deriving data on the space sector from official statistics is the fact that it typically does not represent a single category in existing industrial classifications. The current edition of the UN International Standard Industrial Classification (ISIC), Revision 3.1, includes most parts of the space sector under more aggregate categories. The most relevant of these are:

Class 3530: Manufacture of Aircraft and Spacecraft. This class includes the manufacture of spacecraft and spacecraft launch vehicles, satellites, planetary probes, orbital stations and shuttles.

Class 6220: Non-scheduled Air Transport. This class includes the launching of satellites and space vehicles, and the space transport of physical goods and passengers.

Class 6420: Telecommunications. This class includes the transmission of sound, images, data or other information via satellite.

In all three cases, the space sector is included with much larger industries, *e.g.* aircraft manufacturing for class 3530, regular charter flights for class 6220 and all telecommunications in class 6420. Other segments of the space

The space sector in official statistics *(cont.)*

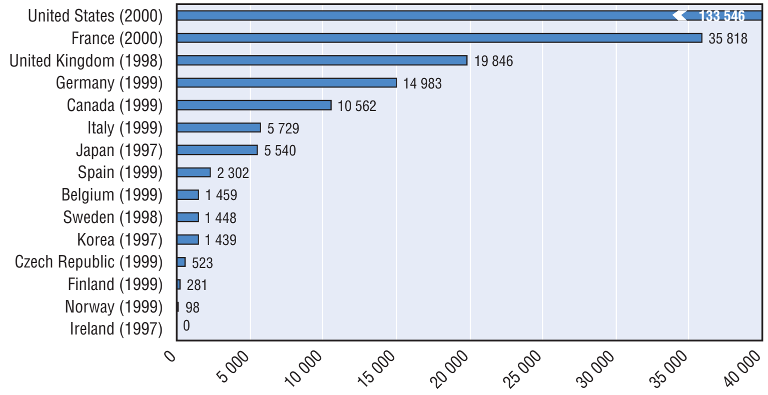
sector that may be relevant are even more disguised in official statistics. For example, ground equipment and communication equipment are included under broader categories in the manufacturing sector. Industry data from official sources that use this industrial classification will therefore not be able to give much detail on the space industry. Related and comparable classifications such as the Statistical Classification of Economic Activities in the European Community (NACE) also provide limited detail. However, NACE provides a distinction for class 6230, Space Transport. The North American Industry Classification System (NAICS) provides more detail than ISIC or NACE, as it distinguishes manufacturing of space equipment from other aerospace.

Certain other official statistics provide useful insight. For example, statistics on exports of space equipment, as well estimates of government budgets devoted to space R&D and of patenting in space-related areas, can be derived from official statistics without great difficulty.

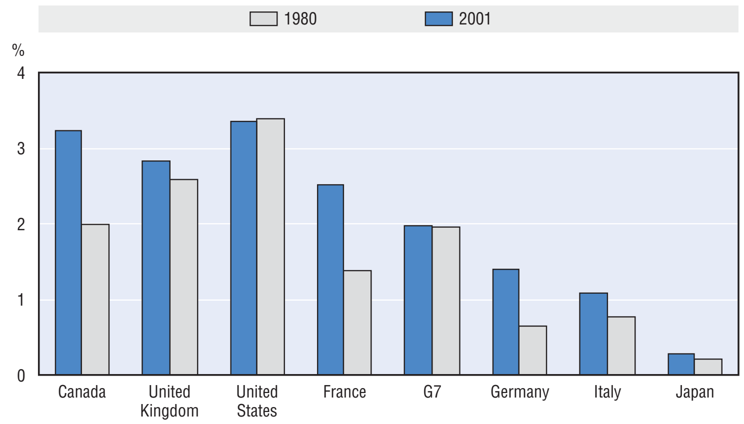
1. Size and growth of the aerospace sector

Figure 1.1. **Production and share of the aerospace industry**

Production, 2001 or latest available year
Millions of current USD using PPPs



Share in total manufacturing value added, 1980 and 2001

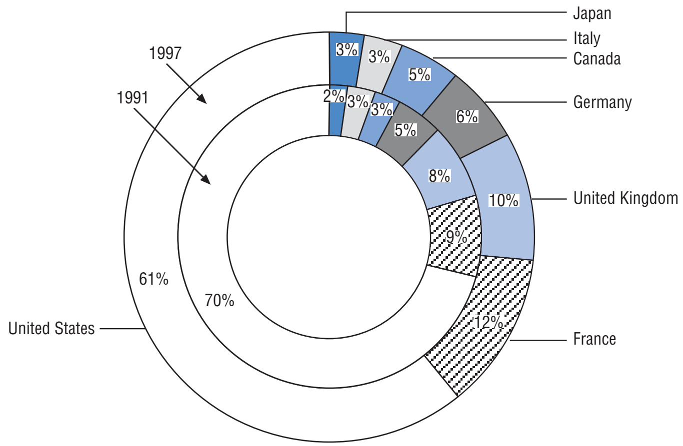


Source: OECD STAN database, 2003.

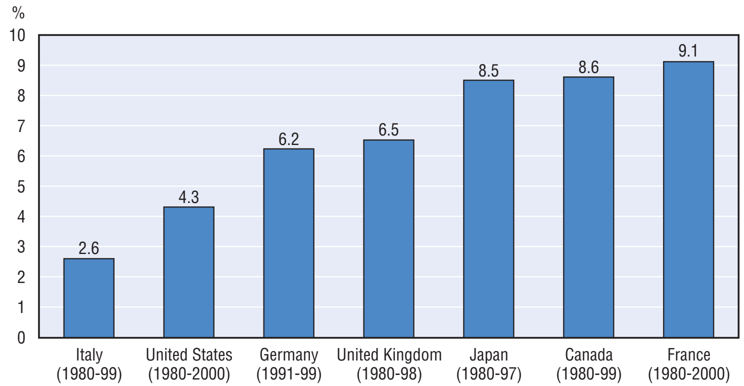
1. Size and growth of the aerospace sector

Figure 1.1. **Production and share of the aerospace industry** *(cont.)*

Aerospace production in the G7 countries, 1991 and 1997
Percentage of total production in G7 countries



Production in the aerospace industry, G7 countries, 1980-2000
Annual average growth (%)



Source: OECD STAN database, 2003.

2. Offical statistics on the US space industry

- Official data capture the US space sector somewhat better. They show a sharp downturn in 2000 and 2001. The share of manufacturing of space equipment (guided missiles and space vehicles) in total manufacturing employment and value added fell from 1999 to 2000, from over 0.5% of total value added over 1997-99 to just over 0.3% in 2000. Employment also fell considerably over this period.
- The experience of the US satellite communications industry is somewhat different. It grew very rapidly from 1999 to 2000, but stagnated in 2001. It remains quite small relative to the total telecommunications industry, accounting for about 2.4% of all revenues in 2001.
- Shipment data for space equipment also show a sharp downturn in 2001. Shipments declined sharply in almost all areas, with the notable exception of complete guided missiles.

The US space sector in official statistics

NAICS provides some detail on the space industry, as it distinguishes manufacturing of space equipment from other aerospace as well as satellite communications. The main categories covering the space industry in the 2002 NAICS are:

Class 336414: Guided Missiles and Space Vehicles.

Class 517410: Satellite Telecommunications.

These aspects of the space industry can thus be distinguished through official data, *e.g.* statistics from the US Bureau of the Census. Other parts of the US space sector are more difficult to locate in official statistics. They include:

Class 334220: Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing. Covers areas such as Global Positioning System (GPS) equipment, equipment for ground stations, satellite manufacturing, satellite communications equipment, etc.

Class 334511: Search, Navigation, etc., Equipment. Covers navigational equipment.

Class 515111: Radio Networks. Includes satellite radio networks.

Class 515210: Cable and Other Subscription Programming. Includes satellite TV networks.

Class 517510: Cable and Other Program Distribution. Includes direct broadcast satellite, direct-to-home satellite systems, satellite distribution systems, etc.

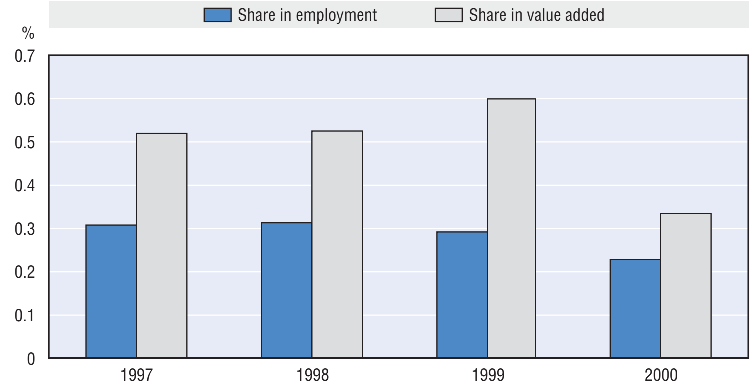
Class 517910: Other Telecommunications. Includes satellite tracking and satellite telemetry.

These areas of the space industry are therefore not available separately from official statistics.

2. Official statistics on the US space industry

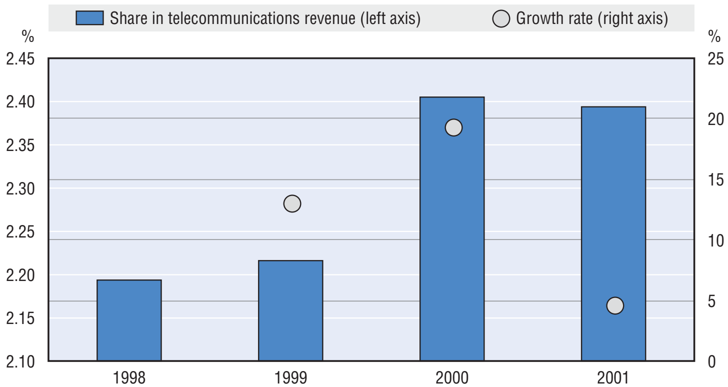
Figure 2.1. **Contribution of the space industry to the US economy**

Share of guided missiles and space vehicles in total manufacturing employment and value added, 1997-2000



Source: US Bureau of the Census, *Annual Survey of Manufactures.*

Share of satellite communications in telecommunications revenue and growth rate, 1998-2001

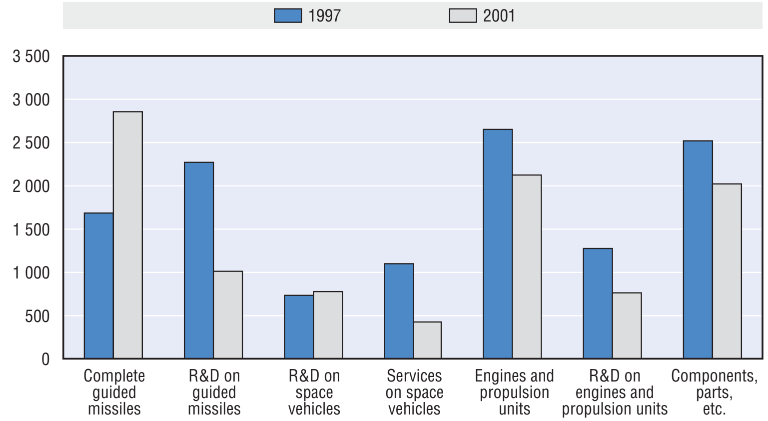


Source: US Bureau of the Census, *Service Annual Survey.*

2. Official statistics on the US space industry

Figure 2.2. **Shipments of the guided missiles and space vehicles industry, 1997-2001**

USD millions



Source: Bureau of the Census, *Annual Survey of Manufacturers*, Value of Product Shipments.

3. Exports of space-related products

- Exports of space equipment account for a relatively small share of total exports. In 2001, they represented little more than USD 3 billion, or less than 0.1% of total manufacturing exports. The share has fallen somewhat over time, as exports of space equipment have declined in value since 1998.
- The United States accounts for over 40% of all exports. The United Kingdom, France and Germany are the other major exporters in the OECD area.
- About two-thirds of exports are destined for other OECD countries, but a substantial share go to non-OECD countries, notably in Latin America and Asia. Detailed analysis of trade flows shows that much of this share is destined for French Guyana, Brazil, Luxembourg, Australia and Singapore, several of which are launch sites for space vehicles.

Measuring trade in space products

Product and trade classifications are more detailed than industry classifications and thus provide slightly more detail on the space industry. However, because trade classifications only cover physical goods, they ignore the services that are a major part of the space sector. The trade classification of the World Customs Organization, the so-called Harmonized System (HS), distinguishes some categories of goods that cover the space industry. The major ones are:

HS 8802.60: Spacecraft (including Satellites) and Suborbital and Spacecraft Launch Vehicles.

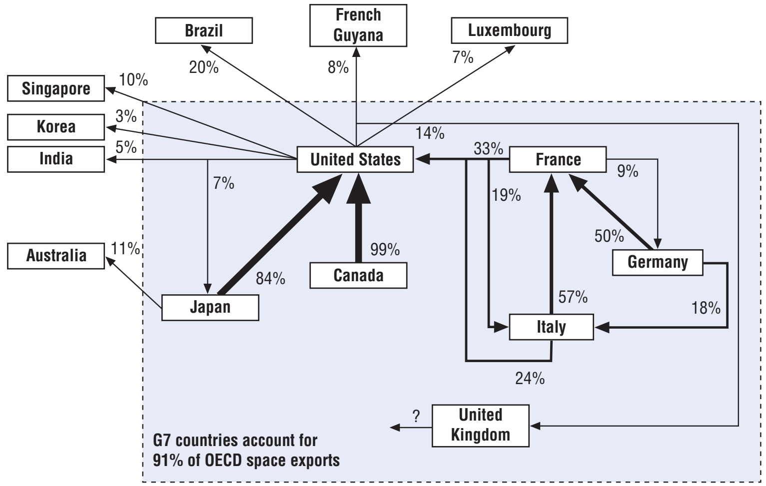
HS 8803.90: Parts of Aircraft And Spacecraft, n.e.s.

Some statistics on trade in space industry products can therefore be derived from international trade statistics. Certain space-related products may be classified as secret, and these cannot be distinguished in international trade data.

3. Exports of space-related products

Figure 3.1. **Exports of space products from G7 countries by country of destination, 2001**

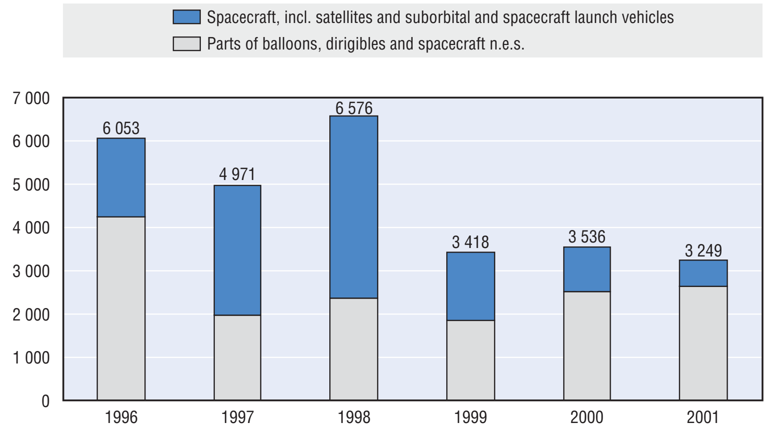
Percentage of total national exports for such products



Note: Only covers countries that attract over 10% of national exports of space products.
Source: OECD, *Annual International Trade Statistics*, 2003.

Figure 3.2. **OECD exports of space products, 1996-2001**

USD millions

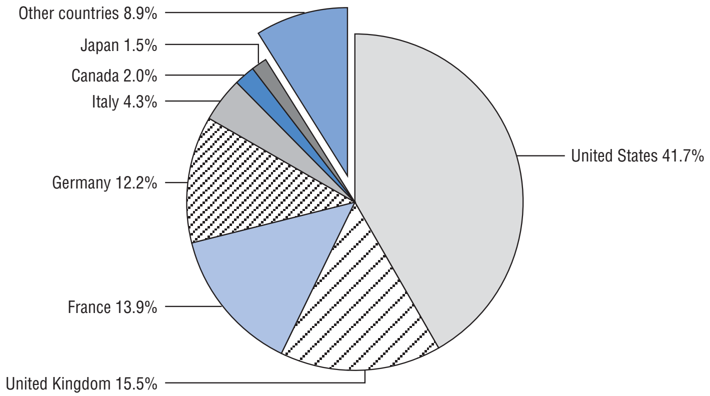


Source: OECD.

3. Exports of space-related products

Figure 3.3. **Share of main exporters in total OECD exports, 2001**

Percentage of total



In 2001, G7 countries accounted for 91% of the USD 3 249 million generated by OECD exports of space products worldwide

Source: OECD, *Annual International Trade Statistics*, 2003.

Table 3.1. **Markets for G7 exports of space products, 2001**

	USD '000	%
Total	**2 461 536**	**100**
OECD countries	1 667 329	67.7
Non-OECD countries	794 207	32.3
OECD countries	**1 667 329**	**100**
of which:		
G7 countries	1 299 576	77.9
Other EU countries	270 712	16.2
Non-OECD countries	**794 207**	**100**
of which:		
America	378 093	47.6
South America	261 578	32.9
Central America	3 421	0.4
Other America	113 093	14.2
Asia	271 978	34.2
Europe	132 633	16.7
Africa	11 277	1.4
Oceania	226	0.0

Source: OECD, *Annual International Trade Statistics*, 2003.

4. Government support for civil space R&D

- In 1999, OECD governments devoted some USD 13 billion to civil space R&D programmes, of which 94% by G7 countries and more than half by the United States.
- The United States not only has the largest budget for space R&D but also the highest share of its budget devoted to space R&D. France (or Europe if counted as a bloc) is second. Japan also makes a large contribution to the OECD-wide public budget for space R&D.
- France, Germany and Italy provide the major part of the European effort, although Belgium and Spain also devote a large share of their public R&D budget to space.
- Relative appropriations to space R&D have changed considerably over time. Shares of space R&D in current public budgets are similar to those of the early 1990s after reaching record levels in the mid-1990s.

Measuring government support for civil space R&D

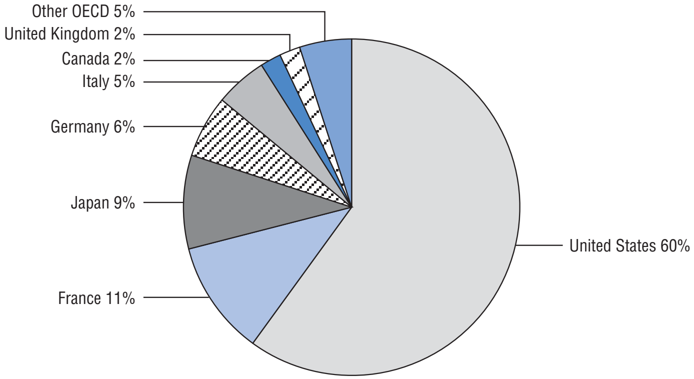
There are two ways of measuring how much governments spend on R&D. The first is to survey the performing units that carry out R&D. The second uses data collected from budgets. The latter are officially referred to as "government budget appropriations or outlays for R&D" (GBAORD). GBAORD measures the funds committed by the federal/central government for R&D to be carried out in one of the four sectors of performance – business enterprise, government, higher education, private non-profit sector – at home or abroad (including by international organisations). Public R&D allocations are also classified by primary socio-economic objective. As a result, GBAORD reflects current government priorities.

GBAORD should not be interpreted as a direct reference to any national government's budgetary practice. Even though some government-supported R&D programmes have a single purpose, others may be supported for a number of complementary reasons. Consequently, GBAORD data are less accurate than performance-based data, and the level of international comparability is probably lower than for other R&D input series covered by the OECD's *Frascati Manual*. For the space category, an additional problem is that part of the budget allocated to space may fall under defence-related R&D, which is not considered here but may be quite substantial in some countries.

4. Government support for civil space R&D

Figure 4.1. **OECD budget for space R&D by country, 1999**

Percentage of total OECD GBAORD to civil space programmes

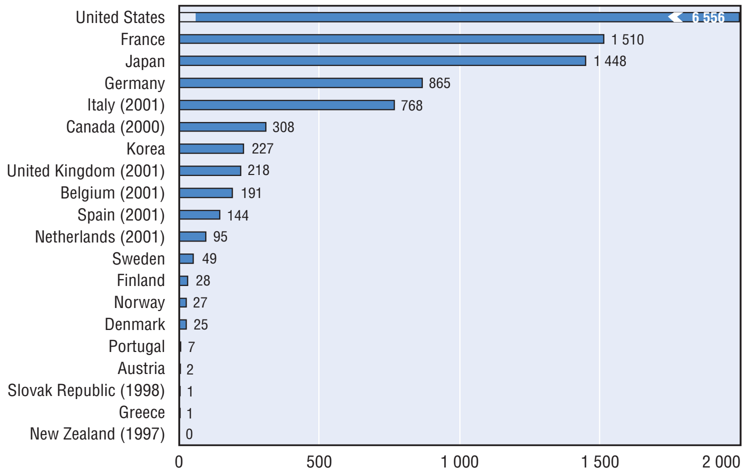


Source: OECD *R&D database*, February 2003.

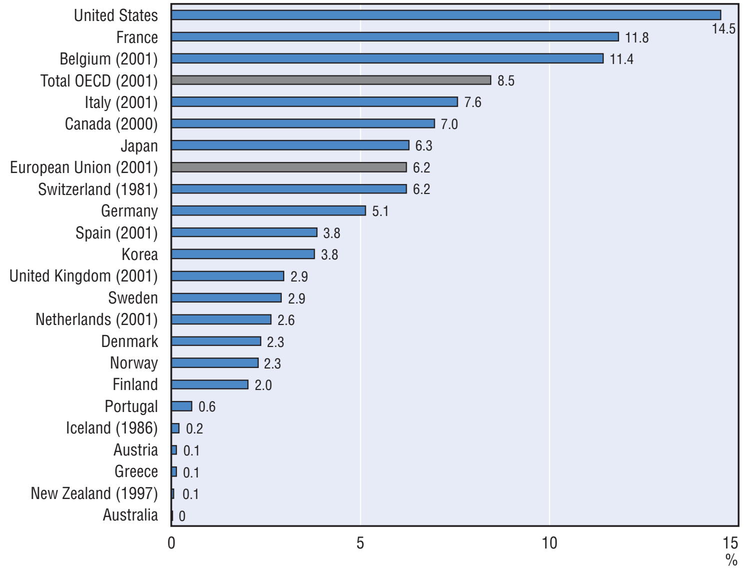
4. Government support for civil space R&D

Figure 4.2. **Civil GBAORD for space programmes in the OECD area, 2002**

Millions of current USD using PPPs



Percentage of total civil GBAORD

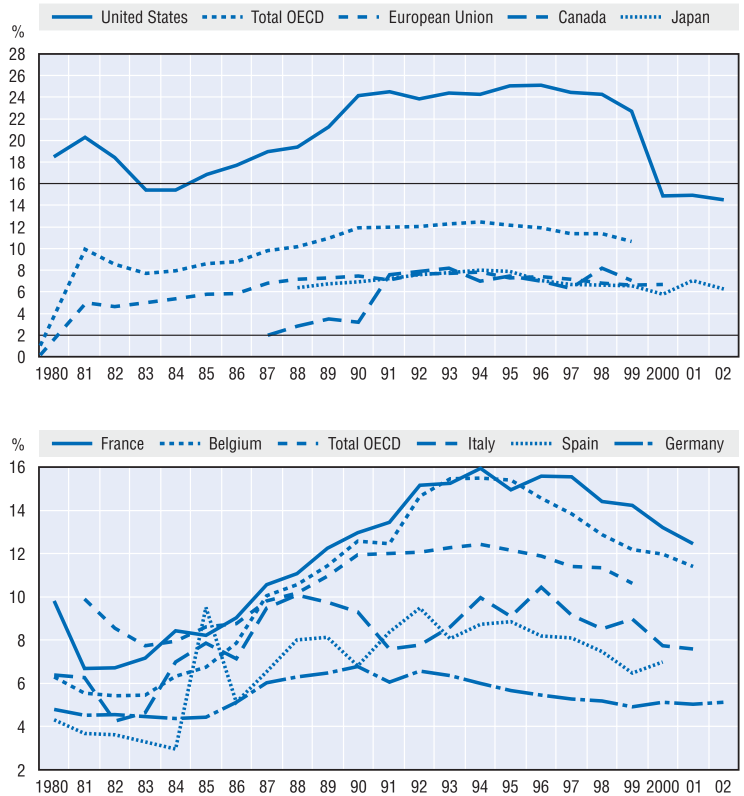


Source: OECD, Main Science and Technology Indicators database, 2003.

4. Government support for civil space R&D

Figure 4.3. **Change in GBAORD to civil space programmes, 1980-2002**

Percentage of total GBAORD



Source: OECD, Main Science and Technology Indicators database, 2003.

5. Business expenditures on aerospace R&D

- A few countries account for most of the business expenditure on aerospace R&D. In 1998 the G7 countries and the United States represented 97% and 61%, respectively, of the USD 23 billion spent on aerospace research in the OECD area.
- However, while R&D expenditures of the aerospace industry increased slightly in most OECD countries, US spending dropped to less than half of its volume a decade ago.
- Given the strong overall expansion of business expenditure on R&D over the past decade, the modest increase in aerospace R&D points to a relative downturn in this area to the benefit of other fields. Between 1987 and 2000, the United States, France and the United Kingdom all recorded sharp drops in the share of aerospace BERD (business enterprise R&D) in total manufacturing BERD.
- This decline also led to lower R&D intensity in the aerospace industry. A comparison of the share of aerospace BERD in total manufacturing BERD and the share of the aerospace value added in total manufacturing value added shows that the aerospace industry is more R&D-intensive than other high-technology industries. However, while the R&D intensity of high-technology manufactures remained stable over time, that of the aerospace industry decreased, notably in Germany and France.

Business expenditure on R&D

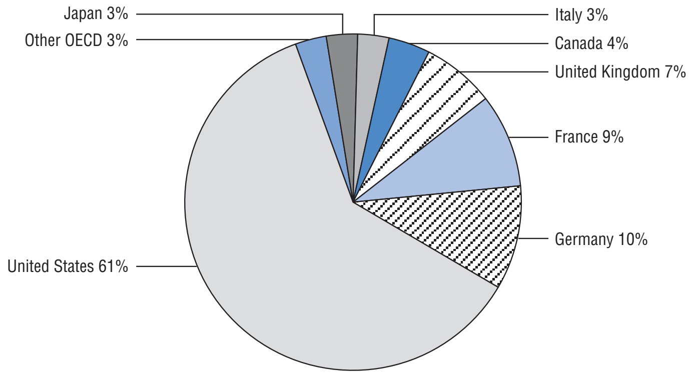
Business enterprise R&D (BERD) covers R&D activities carried out in the business sector by performing firms and institutes regardless of the origin of funding. Industrial R&D is closely linked to the creation of new products and production techniques, as well as to a country's innovative efforts. The business enterprise sector includes firms, organisations and institutions whose primary activity is the market production of goods and services for sale to the general public at an economically significant price and the private and non-profit institutes that mainly serve them.

The estimates shown here are from the OECD ANBERD database. This database was constructed to create a consistent data set that could overcome problems of international comparability and temporal discontinuities associated with the official BERD data provided to the OECD by its member countries. The ANBERD data are thus estimates from official data supplied by national statistical authorities. They are based on ISIC, Revision 3, from 1987 to 2000. This industrial classification only provides estimates for the aerospace industry as a whole; it does not distinguish private R&D related to space equipment.

5. Business expenditures on aerospace R&D

Figure 5.1. **R&D expenditures of the OECD aerospace industry, 1998**

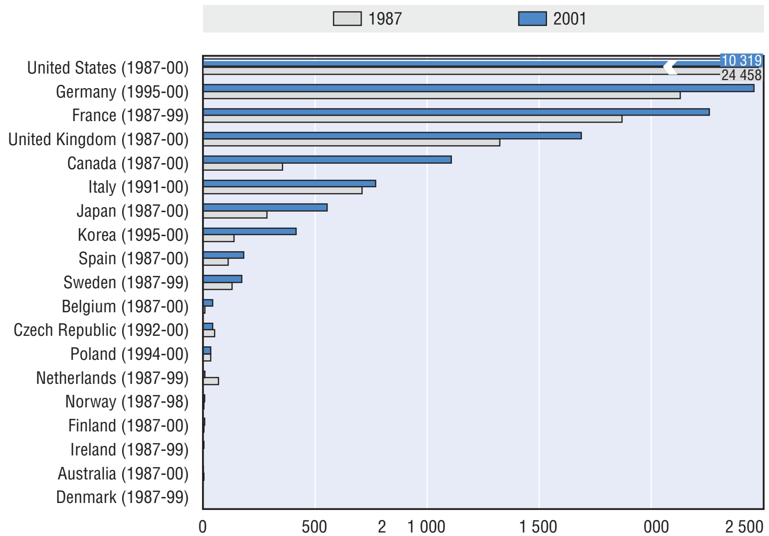
Percentage of total OECD R&D expenditures for the aerospace industry



Source: OECD, ANBERD database, February 2003.

Figure 5.2. **BERD of the aerospace industry, 1987-2001**

Millions of current USD using PPPs

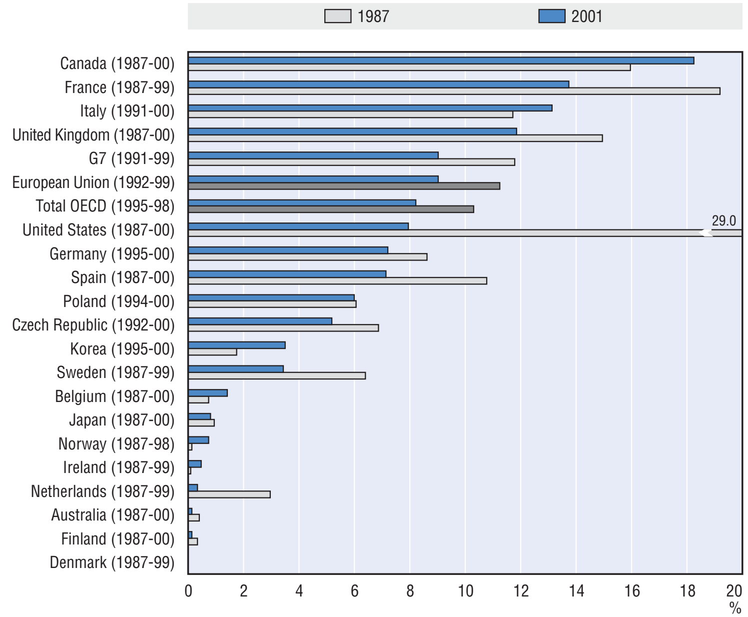


Source: OECD, STAN and ANBERD databases, February 2003.

5. Business expenditures on aerospace R&D

Figure 5.3. **Share of the aerospace industry in total business R&D, 1987-2001**

Percentage of total manufacturing BERD

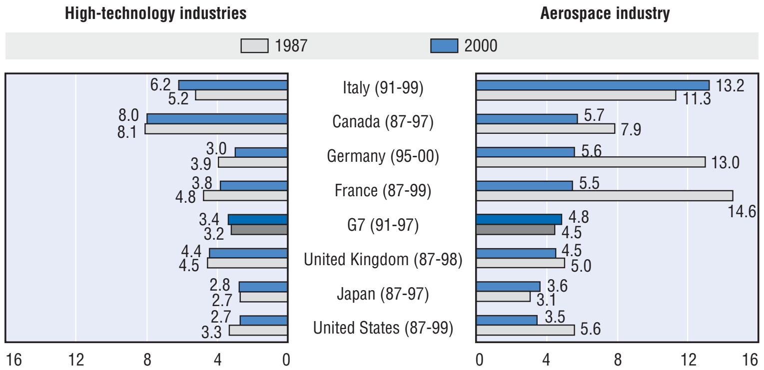


Source: OECD, STAN and ANBERD databases, February 2003.

5. Business expenditures on aerospace R&D

Figure 5.4. **Index of R&D intensity in aerospace and in high-technology industries, 1987-2001**

Ratio between the industry's share in total BERD and in total manufacturing value added



Source: OECD, STAN and ANBERD databases, February 2003.

6. Space-related patents

- Patenting of space inventions is primarily concentrated in OECD countries. Between 1980 and 2001, they were responsible for 97% of all such applications to the European Patent Office (EPO) and nearly all the grants at the United States Patent & Trademark Office (USPTO).
- The United States is the first applicant for space patents to the EPO, with 48% of the total relevant patent applications. It also accounts for more than three-quarters of total grants from the USPTO.
- Among European countries, France and Germany account for the bulk of patents in space-related inventions at both offices.
- France, Hungary, the United States and, to a lesser extent, Spain show a high relative patent specialisation in the field of space. However, while specialisation patterns remained quite constant over time at the USPTO, they changed markedly at the EPO. These differences in specialisation indices reflect the emergence of new patent applicants in the area of space-related inventions.

Patents as indicators of technological performance

A number of surveys have shown the reliability of patent data as an indicator of technological innovation. They have shown that a large proportion of firms' inventions are patented and that a large proportion of patents become innovations with an economic use. Patents reveal inventions and innovations in small firms and in the engineering departments of large firms, which R&D indicators alone do not properly measure.

The simplest type of patent indicator is derived by counting the number of patents that satisfy one or more criteria. Nonetheless, patents do not cover all innovations, as many are protected by other types of intellectual property regimes, or by secrecy.

A description of the patenting activity of individual countries may differ widely, depending on the patent institution considered. This is because an individual country's share in total patenting will depend on the relevance for that country of the particular patent institution. Moreover, a patent's nationality may be defined as that of the inventor or of the country of first filing.

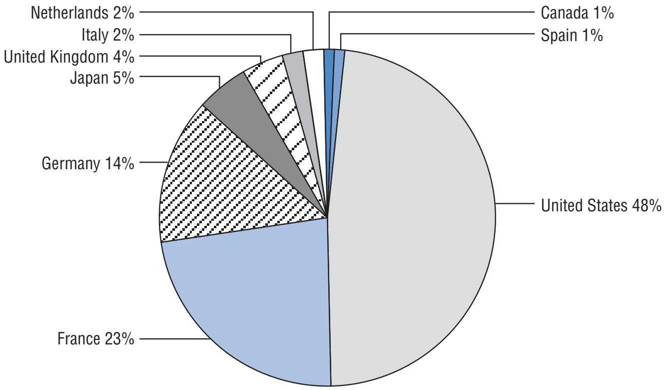
National data on countries' patenting activity can also be broken down by region, in order to investigate the geographical distribution of technological activities. The main methodological problem is how to assign individual patents to regions in a way that reflects the presence of inventive activity, as patents are usually assigned according to the address of the inventor or the firm that owns the patent.

6. Space-related patents

Figure 6.1. **Country share in space-related patenting at EPO and USPTO, 1980-2001**

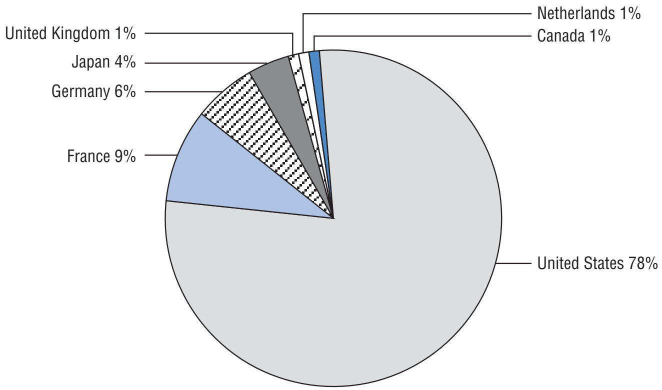
Percentage of total patent applications or patent grants for space-related inventions over the period

Percentage of EPO patent applications for space-related patents



OECD countries account for 97% of total EPO space-related patents applications filed between 1980 and 2001

Percentage of USPTO patent grants for space-related patents



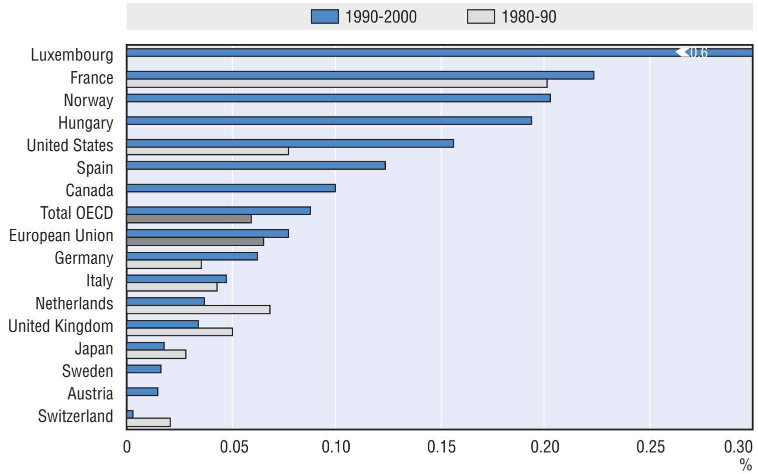
OECD countries account for 99% of total USPTO space-related patents granted between 1980 and 2001

Source: OECD, Patent database, February 2003.

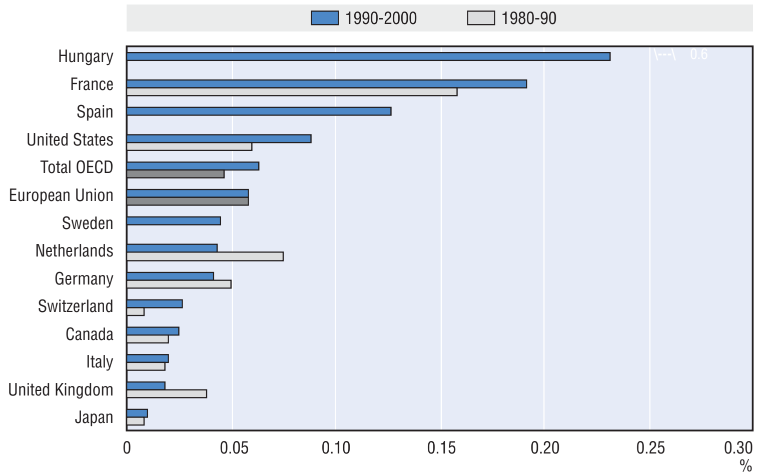
6. Space-related patents

Figure 6.2. **Share of space-related inventions in total national patents, 1980-2000**

Percentage of national patents applications to the EPO



Percentage of patents granted to the country at the USPTO

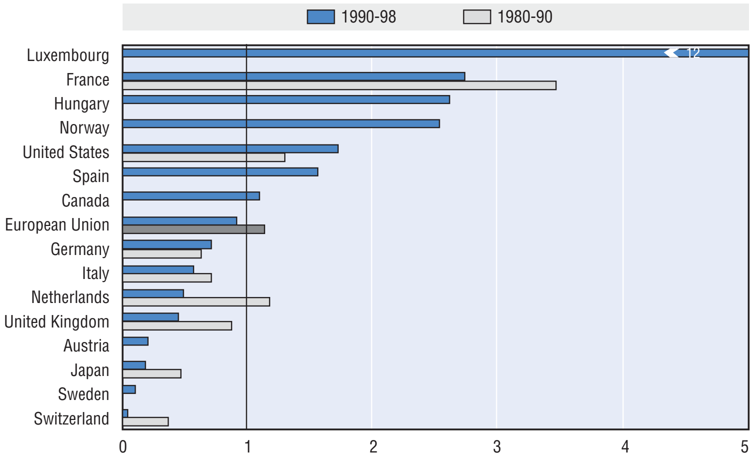


Source: OECD, Patent database, February 2003.

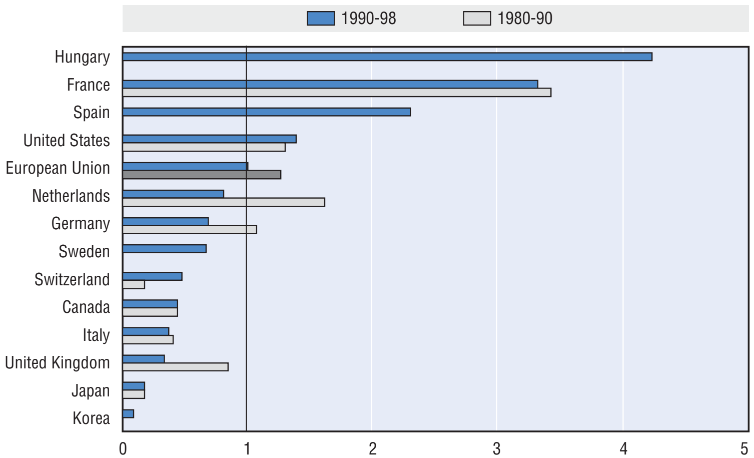
6. Space-related patents

Figure 6.3. **Specialisation in patenting for space-related inventions, 1980-98**

Index based on OECD countries' applications to the EPO



Index based on USPTO grants to OECD countries



Note: The specialisation index compares the country's share in the total OECD stock of space-related patents (granted or applied for) over the period, to the country's share in the total OECD stock of patents in all fields. Indexes above 1 indicate a high relative specialisation in space.

Source: OECD, Patent and MSTI databases, February 2003.

The space sector in private statistics indicators

Measurement of the space sector through private statistics

Private statistics provide considerable detail on the space industry. Typically, the data are collected directly from firms that are active in the industry and often organised through industry associations. Since the industry consists primarily of large, well-organised firms, coverage of the industry as a whole may be good. However, private sources do not always use accepted statistical definitions, and several constraints limit the usefulness of private data.

Private data do not necessarily follow statistical conventions. National statistical offices often develop statistics on an industry's value added and intermediate costs which provide insight into the industry's cost structure and establish a link between the industry and the economy's total value added, *i.e.* total gross domestic product (GDP). Private data typically focus on the sector's sales or revenues and their data on production and revenue may be subject to double counting: some of the production of firms will already have been counted as the production of other firms, as these provide inputs to other firms. Estimates of value added can adjust for this by subtracting the intermediate inputs purchased from other firms and only count the value that is added by each firm.

Statistical offices attempt to classify firms' output in the proper industry and use a breakdown that provides a comprehensive overview of the economy. While this breakdown is currently insufficient for the space sector, it provides a structure that may be lacking in private statistics. This becomes particularly problematic if different private sources do not use the same classification, *i.e.* if some allocate the output of a firm to the space industry, while others allocate it to another industry.

Measurement of the space sector through private statistics *(cont.)*

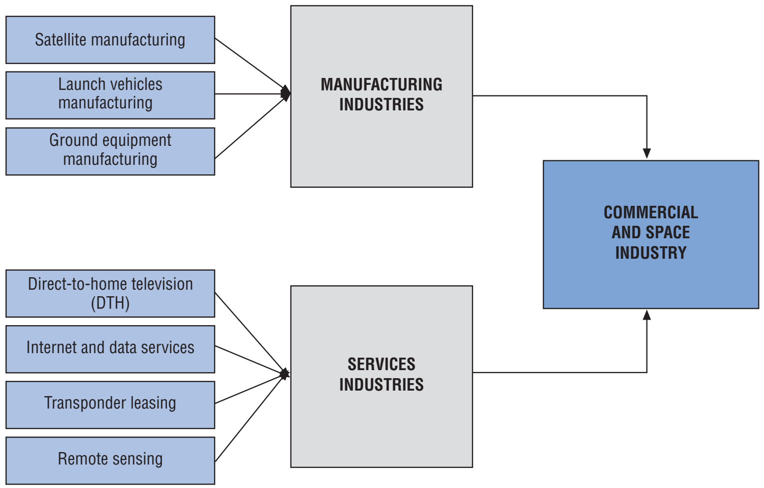
Statistical offices attempt to use methods that are consistent over time. This is not always the case for private sources, with Eurospace being a notable exception.

Statistical offices typically only publish results when they are convinced that the data are reliable. Private sources typically collect data on the basis of surveys, and these may not ensure good coverage of the industry, thereby affecting the reliability of the resulting data.

7. Revenue of the global space sector

- Currently, private data offer the most detail on the principal elements of the space industry. They typically distinguish four main industry segments: satellite communications, space transport, global positioning systems and remote sensing. Satellite communications, including satellite services, transponder leasing, ground equipment manufacturing and satellite manufacturing, account for the bulk of the industry.
- Retail and subscription satellite services, such as direct-to-home television and satellite mobile telephony, account for the largest and most rapidly growing share of this segment.
- The strengths of the United States and the rest of the world are not the same. The United States accounts for the bulk of revenue in ground equipment and satellites, but the rest of world accounts for a larger share of the satellite services market.
- Recent industry forecasts have been very positive, notably for growth in demand for satellite services. Direct-to-home services are projected to account for the largest segment in 2007. It is unclear whether these forecasts have been maintained over the recent economic downturn.

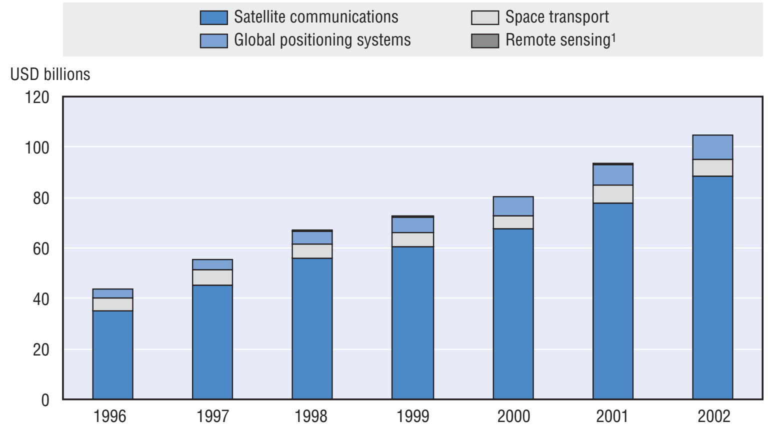
The space sector in private statistics



Source: OECD.

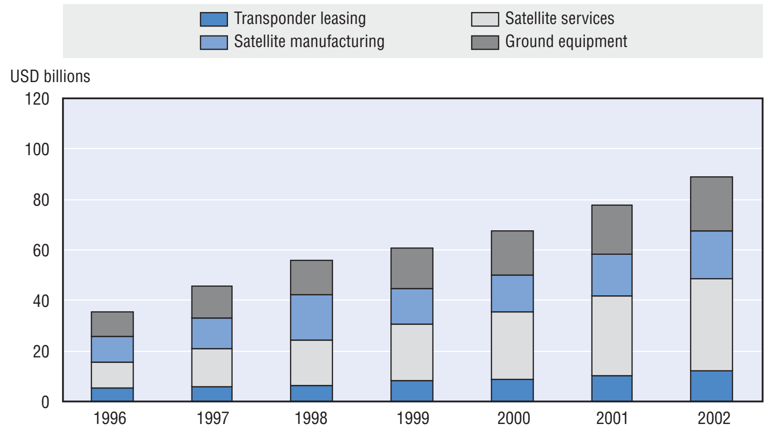
7. Revenue of the global space sector

Figure 7.1. **Total revenue of the space industry, 1996-2002**



Source: OECD.

Figure 7.2. **Revenue of the satellite communications industry**



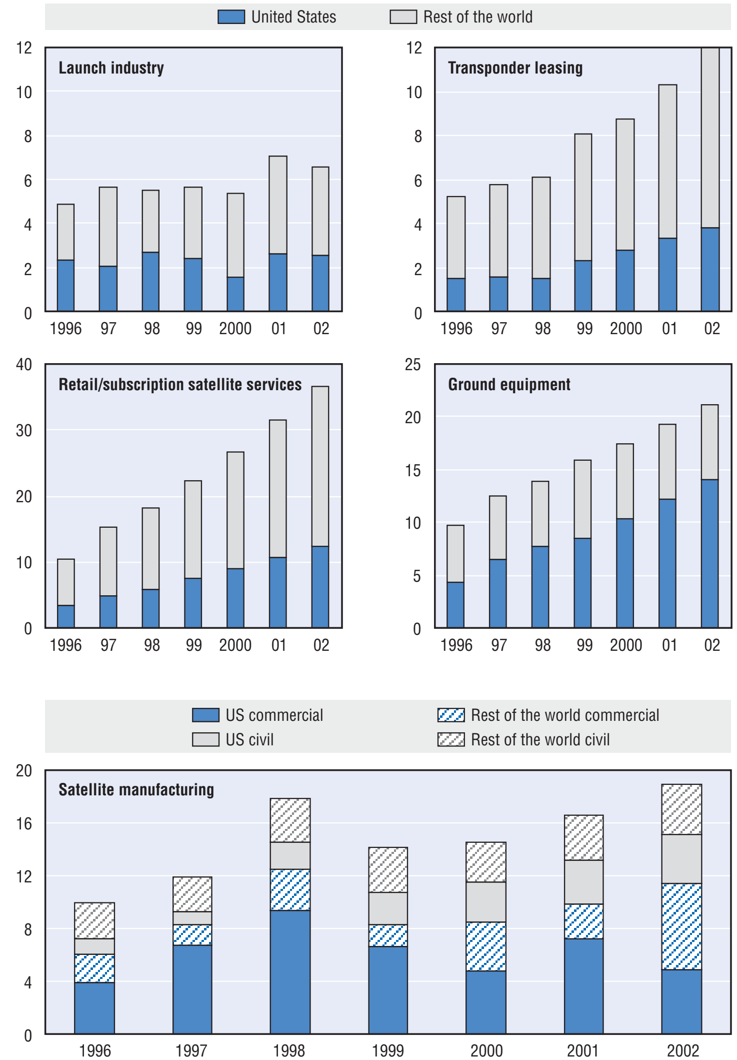
Note: At USD 100 million in 1996 and USD 230 million in 2002, remote sensing is too small to appear on the figure.

Source: US Department of Commerce, Office of Space Commercialization (2002), based on Futron Corporation.

7. Revenue of the global space sector

Figure 7.3. **Detailed revenues of the space industry, 1996-2002**

USD billions

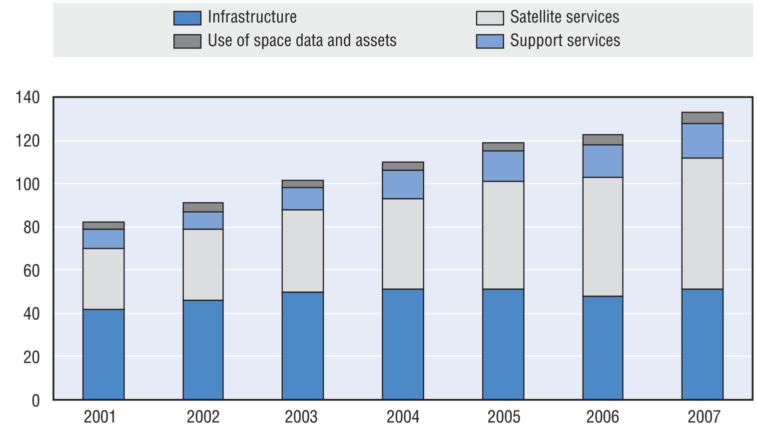


Source: US Department of Commerce, Office of Space Commercialization, Trends in Space Commerce, prepared by Futron Corporation.

7. Revenue of the global space sector

Figure 7.4. **Revenue forecast of the space industry, 2001-07**

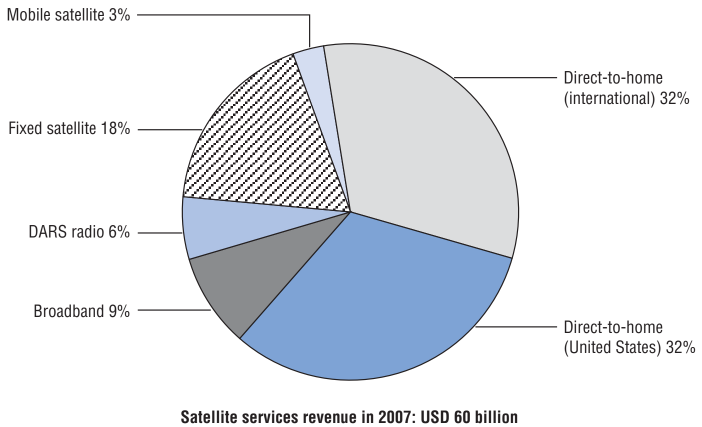
USD billions



Source: International Space Business Council (2002), *State of the Space Industry*, quoted in British National Space Center, The Draft UK Space Strategy.

Figure 7.5. **Projected composition of the satellite services industry, 2007**

Percentages



Source: International Space Business Council (2002), *State of the Space Industry*, quoted in British National Space Center, The Draft UK Space Strategy.

8. Employment in the space industry

- Private statistics offer the most detail on overall employment in the space industry. Official statistics do not provide detail on many industry segments, notably those relating to satellite communications and services associated with the space industry.
- Private data suggest that just under 250 000 persons were employed in the space industry in 2002, about half of them in the United States. For the United States, this accounts for less than 0.1% of total employment. For the rest of the world, the percentage is likely to be lower, although the space industry may have a somewhat higher share of employment in some countries.
- Detailed employment estimates show that satellite manufacturing accounts for about half of all employment in the industry. The manufacturing of ground equipment and the launch industry are also relatively large segments, accounting for some 90 000 persons worldwide in 2002.
- Other parts of the industry account for a very small share of employment. Employment in transponder leasing and satellite services is quite small but growing rapidly. Employment in remote sensing is also very small, accounting for less than 6 000 persons in 2002.

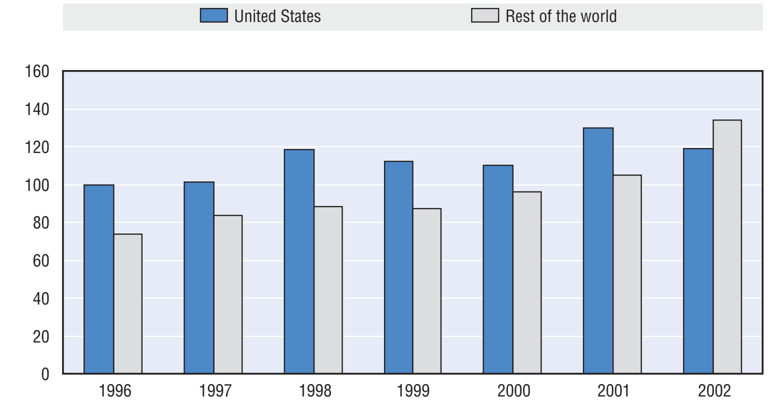
Measurement of employment through private statistics

Private statistics on employment are collected in a way similar to data on revenue, *i.e.* they are often collected directly from firms active in the industry and often through industry associations. Since the industry consists primarily of large and often well-organised firms, this approach may give good coverage of the industry as a whole. Measuring employment is relatively straightforward and, unlike revenue, not subject to double counting.

8. Employment in the space industry

Figure 8.1. **Total employment of the space industry, 1996-2002**

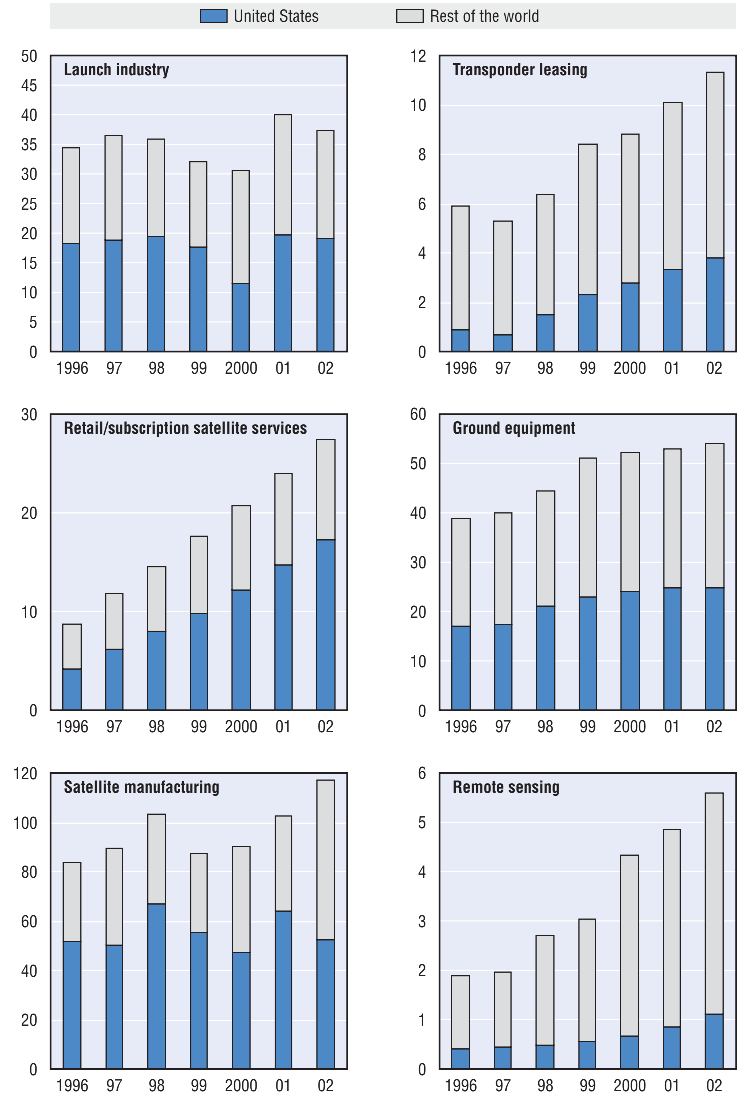
Thousands



Source: US Department of Commerce, Office of Space Commercialization, Trends in Space Commerce, prepared by Futron Corporation.

8. Employment in the space industry

Figure 8.2. **Detailed employment in the space industry, 1996-2002**



Source: US Department of Commerce, Office of Space Commercialization, Trends in Space Commerce, prepared by Futron Corporation.

9. Structure of the European space industry

- Evidence for the European space industry primarily comes from private data, notably from Eurospace. According to Eurospace data, the European space industry accounts for less than 0.1% of total turnover in almost all European countries, with France the major exception. The space sector is largest in France, Belgium and Italy and very small in Ireland and Portugal.
- The four largest European countries account for almost 86% of total turnover and for over 84% of total employment in the space industry.
- Telecommunications, Earth observation and launcher production and development are currently the largest segments of the European space industry. Commercial contracts as well as contracts for the European Space Agency (ESA) and Arianespace are the European space industry's main customers.

Measurement by Eurospace of the European space sector

Data from Eurospace, the official organisation of space system manufacturers and launch system operators in Europe, provide helpful information on the European space industry, but they result in a considerably lower estimate for the European space industry's total turnover than the estimates from Futron presented in Section 7.

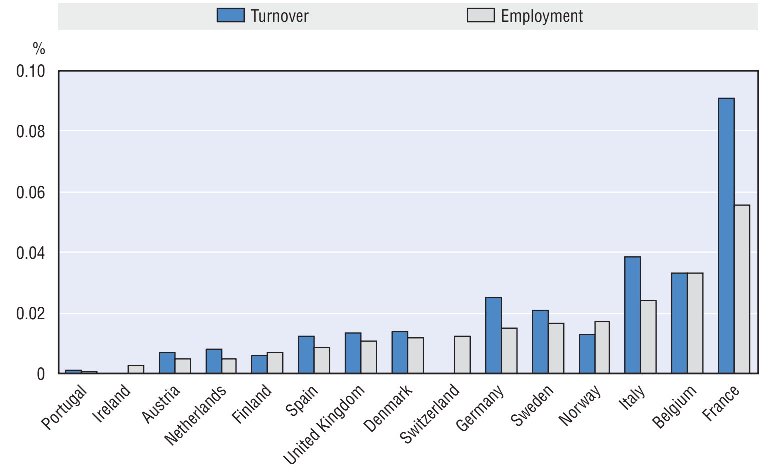
The Eurospace estimates are based on a survey of companies in the space sector, cross-checked with public databases and official sources. Contrary to those of many private sources, Eurospace data are well documented. Eurospace defines the space sector as all companies involved in the design, production, maintenance, test and sale of space-qualified hardware and software and directly related ground elements. Its survey does not include revenue from satellite operators such as Eutelsat or SES or from sales of consumer-market space products. This is a narrower definition of the industry than that used above, hence the industry's smaller contribution to overall economic activity.

The Eurospace revenue data attempt to correct for double counting, by asking only for firm's internal turnover, *i.e.* the amount of the space contract actually done in-house. As a result, the revenue data are lower than those presented above and likely to be closer to value added.

9. Structure of the European space industry

Figure 9.1. **The European space sector**

Percentage of total turnover and employment

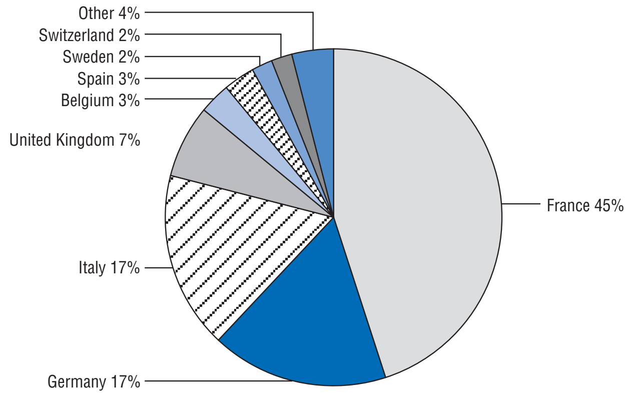


Source: Eurospace, *The European Space Industry*, 1996-2001, Paris, March 2003.

9. Structure of the European space industry

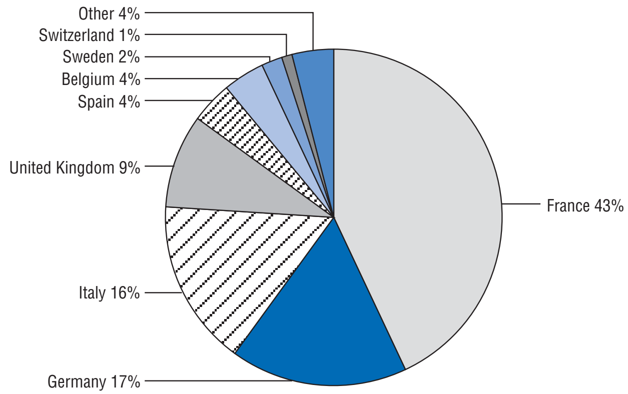
Figure 9.2. **Turnover and employment in the European space industry**

Turnover



Turnover in 2001: EUR 5 258 million

Employment



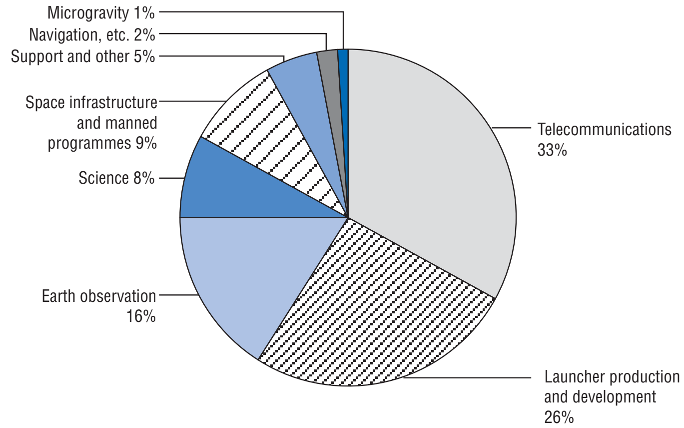
Employment in 2001: 34 727 persons

Source: Eurospace, *The European Space Industry*, 1996-2001, Paris, March 2003.

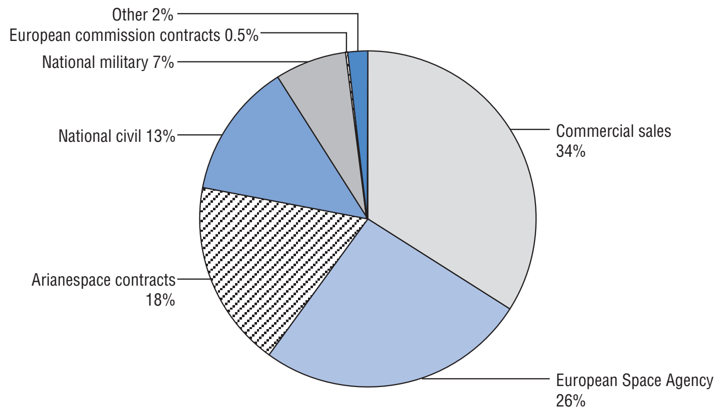
9. Structure of the European space industry

Figure 9.3. **Activities and customers of the European space industry**

Turnover by activity



Turnover by customer



Source: Eurospace, *The European Space Industry*, 1996-2001, Paris, March 2003.

10. Public budgets for the space sector

- Governments carry a substantial part of expenditure on the space industry, as some parts of a country's space-related efforts (*e.g.* R&D) are of a public nature and would not necessarily be carried out by private industry.
- Most public sector agencies publish some information on space budgets, but some of the most comprehensive information can be found at private institutions. These suggest that the United States accounted for over 80% of public budgets for space programmes in 2001. This is true even though military budgets are not fully taken into account. France and Japan follow in terms of their budgets for space programmes. The United States has the largest budget for space compared to the size of its economy, as measured by GDP. France also devotes more than 0.1% of GDP to space.
- The US budget for space has fluctuated over time, with a peak in the late 1960s, at the time of the Apollo programme, and an increase into the late 1980s. The bulk of the space budget goes to the National Aeronautics and Space Administration (NASA) and the Department of Defense.
- The United States accounts for the bulk of the civil budgets for space. The largest areas of expenditure are space transport, space science and Earth observation. Countries participate to different degrees in the various space-related activities.

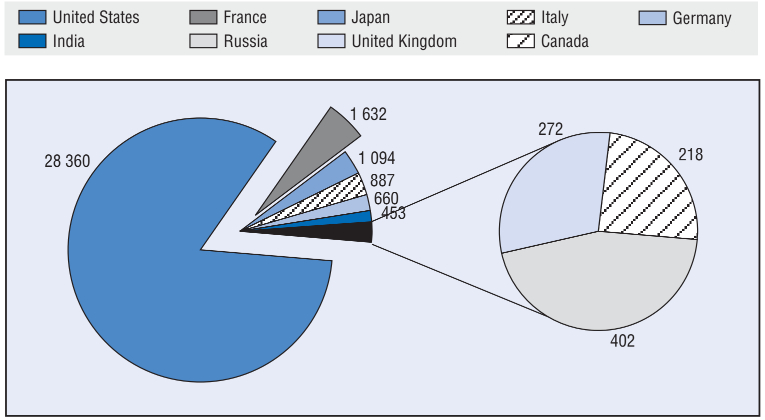
Measuring public budgets and expenditure

Most governments publish information on the budgets allocated to space. Collecting this information across the main actors in the space sector provides a first glance at government involvement and differences among countries. There are several difficulties with these data, however. First, budgets do not necessarily match expenditure; more or less may be spent than is allocated in the budget. Second, budgets do not necessarily cover all expenditures devoted to space. Some expenditures, *e.g.* for military purposes, may be secret. Moreover, some expenditures may be classified under other areas of government expenditure, *e.g.* telecommunications or R&D. Third, comparing the size of budgets across countries raises issues of comparing costs. Expenditures in low-income countries such as China and India may have a higher purchasing power than similar expenditures in high-income countries, as the costs of labour and services are lower. The real, *i.e.* purchasing power parity-adjusted, expenditure in such countries may thus be higher than what is indicated by a comparison based on exchange rates.

10. Public budgets for the space sector

Figure 10.1. **Public budgets for space programmes**

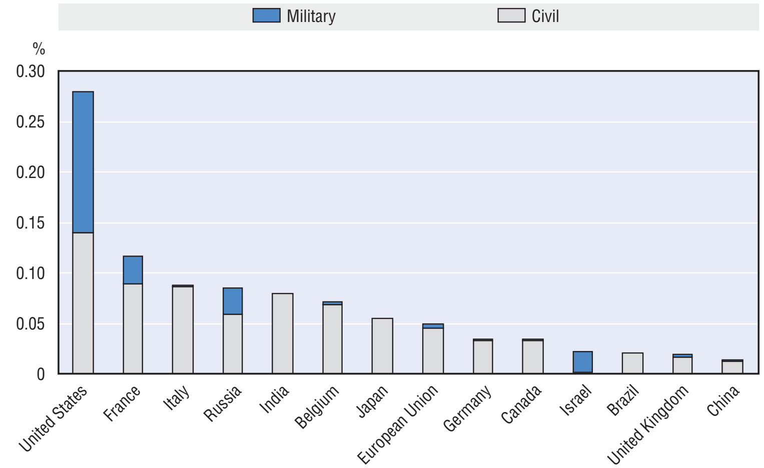
USD millions



Source: Euroconsult, 2002.

10. Public budgets for the space sector

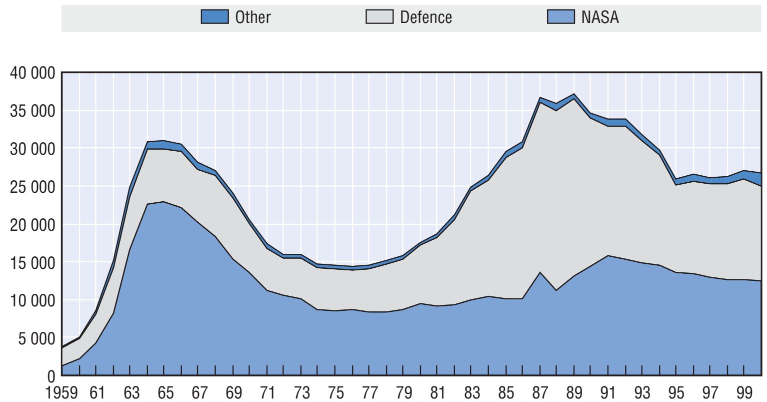
Figure 10.2. **Public budgets for space programmes**
Percentage of GDP



Note: Budget data for military purposes were estimated for Italy, Germany, Russia and the United Kingdom.

Source: Euroconsult (2002), *World Market Prospects for Public Space Programs*, 2002 edition.

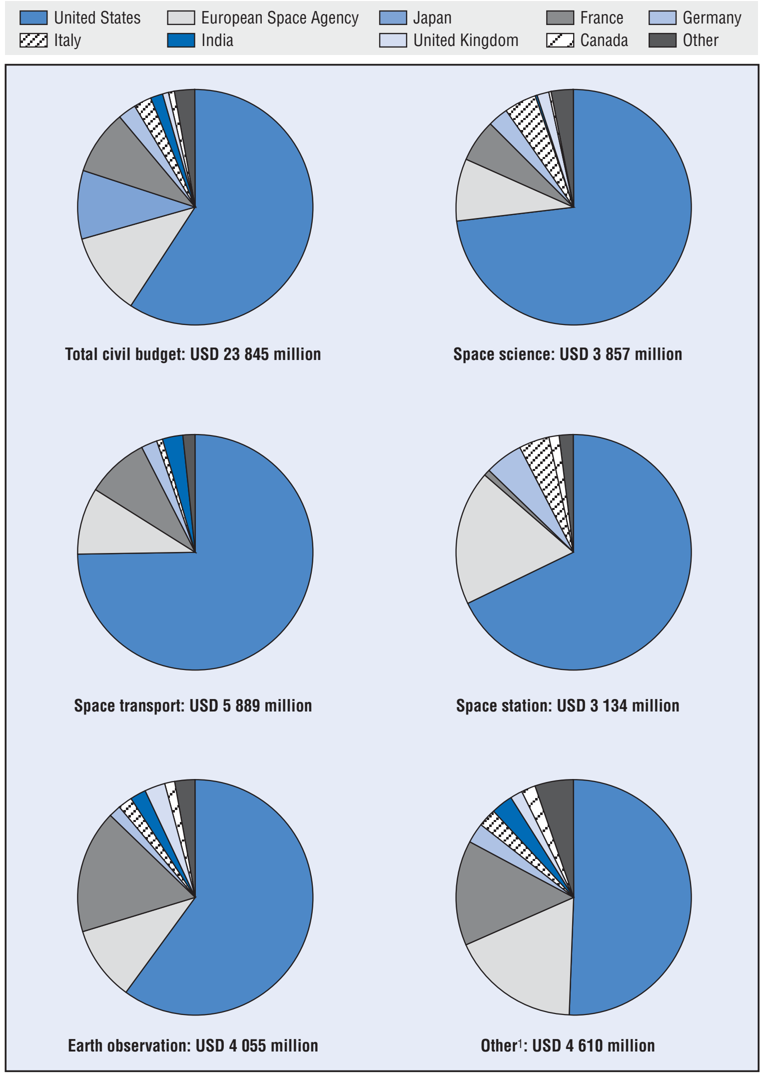
Figure 10.3. **US public budgets for the space sector**
Millions of 1999 USD, 1959-2000



Source: US Office of Management and Budget.

10. Civil budgets for the space sector

Figure 10.4. **Civil budgets for space programmes by activity, 2001**



Note: Other includes budgets for microgravity and commercial exploration of space, telecommunications and others, including administration.

Source: Hertzfeld and Ojalehto, quoted in CT Brasil, 2002.

Additional bibliography

Space Economic Data (December 2002), prepared for the US Department of Commerce, Office of Space Commercialization, by Henry R. Hertzfeld, The George Washington University, Space Policy Institute.

ANNEX B

Main trends and factors

This annex reviews the main trends and factors likely to influence over the next 30 years or so the drivers of change (geopolitical developments, socio-economic developments, energy and the environment, and technology) used in the construction of the scenarios presented in Chapters 2 and 3. The review draws from a variety of sources, including the studies commissioned for this report.

Given the long time horizon adopted here, the trends and expectations described below are not cast in stone, nor do they represent the views of the OECD. They merely reflect the opinions expressed by experts in the recent literature. Moreover, because they are drawn from reports or papers prepared by specialists in various fields, they are not necessarily consistent. They offer only a preliminary, impressionistic vision of the future.

In scenario analysis, as in most forms of inquiry, it is necessary to take a simplified view of reality, *i.e.* to build a model as a way to focus on the issue at hand. This review offers a first-cut appreciation of how important aspects of the world environment may change over the next three decades. It serves as the basis for identifying the major uncertainties underpinning the formulation of scenarios in Chapters 2 and 3.

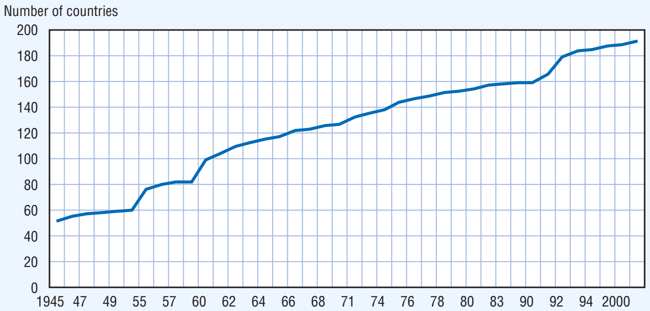
Geopolitical trends and factors

On the political front, most experts tend to expect a relative decline in the position and role of the nation-state. As a result, secessionist movements may more readily wrest power from central governments, and a growing number of regional entities may achieve statehood. The weakening of nation-states may also be reflected in a rising number of failed states. In contrast, international organisations, non-state actors, including multinational corporations and non-governmental organisations (NGOs), but also organised crime and terrorist groups, are likely to become more powerful. Nonetheless, the nation-state should remain the main focal point of international relations, although the pecking order is expected to change. While the United States should remain on top, other players will move up and gain status as regional powers. China may even be in a position to challenge the United States at the global level by 2030, the end of the period considered here.

On the military front, future conflicts are expected mainly to be intra-state and increasingly to involve non-state actors, such as terrorist groups or organised crime. The proliferation of weapons of mass effect (WME) will heighten security concerns in most countries. In response, the United States (which will remain the dominant military power over the period) is expected to adopt, at least initially, a dual strategy of homeland security (including the construction of a national missile shield) and of pre-emptive use of military force abroad. The Europeans, too, are expected to strengthen security at home and to consolidate their collective defence. China, India and Russia are likely to enhance their military capability and to seek to deter US conventional intervention through their WME.

Political

Box B.1. **Growth in membership of the United Nations**



Source: UN, 2003.

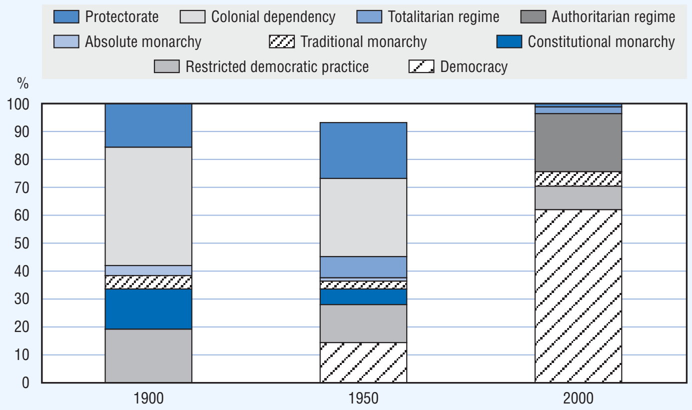
The figure can serve as an indicator of the growth of sovereign states in the second half of the 20th century. UN membership grew steadily from 55 members in 1945 to 191 in 2002, largely following the creation of new nation-states. Three accession periods can be identified:

- 1950s: Consolidation of the organisation with the accession of existing states and new states in the Middle East.
- 1960s and 1970s: End of colonisation and African and Asian accession.
- 1990s: End of communism and Eastern European and Central Asian accession.

Whereas the first waves of new countries were liberated colonies, new nations increasingly result from the secession of regions from existing nation-states. This trend will probably continue in the 21st century.

- *Decline of the role of nation-state.* Its fields of competence may diminish as it loses ground in favour of larger and smaller entities:
  - Political, security and regulatory functions are increasingly transferred to multinational or international bodies.
  - Domestic functions (education, welfare, healthcare) may be transferred to sub-national entities. Regions with an appropriate size and industrial mix may flourish in the global market, while others may be left behind, resulting in growing regional inequalities.
- *Decline in national sovereignty.* Even in fields where the state retains its competence, its ability to exercise discretion in governing its territory may be reduced both *de facto* and *de jure*:
  - Externally, government action is likely to be increasingly constrained by the emergence of international governance and a growing body of international law, as well as by self-imposed treaties and alliances.
  - Internally, new constraints may result from a more explicit and broader definition of the rights of citizens.
  - The growing interdependence of nation-states will mean that the impact of independent action needs to be carefully considered each time, to minimise unintended adverse consequences.
- *Increase in the number of states.* Owing to the reduced role of the nation-state, secessionist groups may succeed in creating new nations. Advances in international law and globalisation may make smaller nations and local governance more viable.
- *Increasing occurrence of failed states.* A growing number of nations will become vulnerable to internal conflicts or pressures from powerful non-state actors:
  - Non-state actors will play a growing role.
  - Multinationals will increase in size and exercise greater power.
  - International criminal and terrorist groups will be able to take advantage of gaps in international law and security arrangements, as well as of safe havens in failed states.
  - NGOs will increasingly influence the international policy agenda.
- *New challenges for world security.* In addition to nuclear weapons, new forms (biological, chemical) of WME, which will be increasingly easy and cheap to produce, will emerge. This could mean:
  - Proliferation of WME in a growing number of nation-states.
  - Increasing potential for these weapons to become available to non-state actors.

Box B.2. **Tracking polity in the 20th century**



Source: Freedom House, 2003.

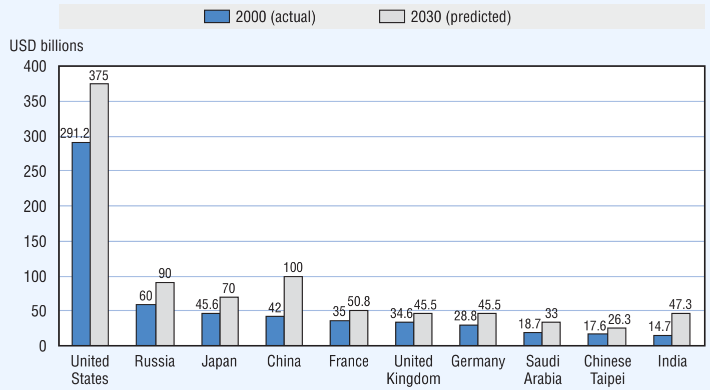
The data collected by Freedom House show the evolution of political regimes in the 20th century. The findings were reviewed by a team of scholars consisting of Professor Orlando Patterson of Harvard University; Professors Seymour Martin Lipset and Francis Fukuyama, both of George Mason University; Dr. Fareed Zakaria, the Managing Editor of Foreign Affairs magazine; and Dr. Marc Plattner, co-director of the International Forum for Democratic Studies and editor of the Journal of Democracy. Adrian Karatnycky, President of Freedom House, and Arch Puddington, Vice President for Research, also took part in the review of the data.

As can be seen, using universal suffrage for competitive multiparty elections as a standard, there were no democracies in 1900. This is mainly due to restricted voting rights for women (Europe) and ethnic minorities (women and Afro-Americans in the United States). At mid-century, the defeat of Nazi totalitarianism, decolonisation and the post-war reconstruction of Europe and Japan resulted in an increase in the number of democratic states. By the end of the century, liberal and electoral democracies clearly predominated. The difference between electoral and liberal democracies should be noted. Freedom House regards liberal democracies as countries respectful of basic human rights and the rule of law. This applies to 70% of existing democracies, or 44% of the total number of polities.

- *Change in the global power balance.* Over the next 30 years or so, the United States is likely to remain the dominant power. However, large developing countries such as China or India may become regional hegemons, and may even be able to challenge the United States as global leader towards the end of the period. If Europe's integration process is successful, it may also emerge as a major world actor. In addition, the increasing geographic concentration of fossil fuel reserves in the Persian Gulf and the Caspian Sea is likely to give these countries extra geopolitical leverage.

Military

Box B.3. **Military spending**



Source: JDCC, Strategic Trends 2015.

The Joint Doctrine and Concept Centre in the British Ministry of Defence has projected selected countries' defence spending for the next 30 years. While according to these estimates, the United States will continue to be the world leader, there will be two major changes. China will become the world's second spender in 2030, and India will have overtaken the United Kingdom as the sixth global spender after tripling its defence budget. Global average spending will rise significantly. However, if the EU is taken as a whole, it would be the second spender, especially in light of its enlargement up to 2030.

- *Future conflicts:*
  - The frequency of open interstate conflicts will remain low because of their potential for greater risks and worse consequences.
  - Surrogate wars that prevailed in the cold war period are less likely to occur.
  - If and when such conflicts occur, they will be very costly.
  - More intra-state conflicts are expected as a result of globalisation, which tends to facilitate cultural conflicts, penalise ineffective governance and facilitate the activities of secessionist movements.
  - Conflicts involving non-state actors, notably terrorists and organised crime, may be more frequent.
- *Future balance of military power* (based on projected growth and constant proportion devoted to defence):
  - The United States will remain the main spender (an estimated USD 375 billion in 2030).
  - China and India will probably experience the largest increase in their military budget.
  - The European Union is likely to be the second spender in 2030 (over USD 150 billion) and China the third (USD 100 billion).
  - China and Russia may develop multi-regional capability by 2015.
- *Proliferation of weapons of mass effect:*
  - Some states will continue to seek to acquire WME to protect themselves from regional threats, increase their global/regional influence and/or deter intervention from the West or emerging global powers.
  - The number of states possessing biological weapons is likely to increase.
  - Proliferation of WME and their means of delivery will increase, particularly biological weapons and asymmetric delivery techniques (civil aircraft, ships, sleeper devices).
  - Non-lethal WME may also be developed (electromagnetic pulse weapons, catastrophic computer viruses) and cause widespread damage without loss of lives.
  - The proliferation of WME to non-state actors will be a key security threat.
  - In the face of these threats, the United States will probably develop an anti-ballistic missile system, either unilaterally or on a multilateral basis with its allies.
  - This may encourage states such as Russia and China to enhance their missile capability and asymmetric delivery mechanisms.

- *Military strategic posture:*
  - The United States may engage in pre-emptive military action against key proliferation states. This may encourage others to speed up their programme or to make their programme more covert.
  - Up to 2015 the United States is likely to have a dual strategy of homeland defence and assertive pre-emptive use of military force abroad. After that, its strategy may be re-evaluated in the light of the results and the impact on state and non-state actors.
  - Europeans will continue to concentrate their attention on collective defence and stabilisation operations. They may also give increased importance to domestic security.
  - China, Russia and India will seek to deter US conventional intervention through their WMEs. China and India will increase their conventional power capability.
  - Both state and non-state actors will employ asymmetric strategies more often.

Socio-economic trends and factors

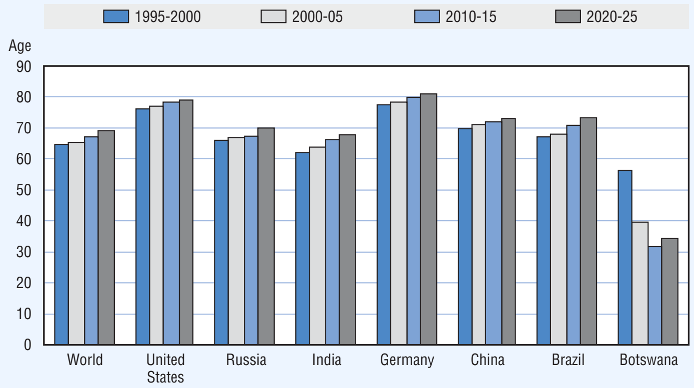
On the demographic front, world population will continue to rise, but growth is expected to slow, with the entire increase taking place in the developing world. Population ageing will become a global phenomenon, although it will be more pronounced in the West and in certain non-western countries, notably China and Russia. The move from the country to cities will accelerate in developing countries, requiring massive investment in infrastructure. More people will also migrate from the developing world to the West. This may spur innovation but could also be a continuing source of tension in Western societies. Culture will become increasingly globalised, fueling bouts of fundamentalism. In contrast, Western societies are likely to become more secular, pragmatic and individualistic, as well as more difficult to govern, as respect for established authority declines.

From an economic perspective, the world may become a better place for more people in the next 30 years. Not only is population growth slowing, but the economy may improve if the globalisation process continues, as major new technologies come on stream and spur growth. However, economic risks will tend to increase: poor governance both at national and international levels is likely to be more severely penalised by markets, and economic shocks may have devastating ripple effects in an increasingly interdependent world. Moreover, income inequalities are expected to rise, both within and among countries, and unemployment may be a major source of unrest in countries in demographic transition. Poverty should decline overall, but will be increasingly concentrated in certain regions of the world, notably Africa and South Asia.

Social

Demography

Box B.4. **Life expectancy at birth, selected countries and world**



Source: UN, 2002 World Population Prospects.

The above figure shows changes in life expectancy at birth in selected countries and the world average between now and 2025, according to the projections of the UN population medium model. Average life expectancy worldwide will increase by close to 8% from 64.1 to 69.1 years. Industrialised countries and China will experience a more moderate increase (less than 3%). Overall, the life expectancy gap between industrialised and developing countries will be reduced but will remain significant.

Countries such as Botswana will experience reduced life expectancy, mainly owing to the HIV/AIDS epidemic.

- *World population trends:*
  - Although the size of the world population should increase from the current 6.1 billion to perhaps 7.2 billion in 2015 and 8.2 billion in 2030, growth should slow (from 1.3% a year today to 1% a year in 2015).
  - Most of the increase will take place in the developing world and in "immigration countries". The bulk of it may be in China, South Asia, Indonesia, the Middle East and North Africa.

Box B.5. **Quantitative population indicators, 1900, 1950, 2000 and 2050**

Variable	Unit	1900	1950	2000	2050
Aggregate population					
Population size	Billion people	1.65	2.5	6.1	8.9
Annual increment	Million people	10	47	78	33
Population growth rate	%/year	0.61	1.88	1.28	0.37
Percentage of population in more developed regions	% of people		32	20	13
Urban population	Billion people	0.21	0.75	2.87	5.43
Median age	Years		24	26	38
Children (up to 15 years)	% of population		34	30	20
Older persons (60 years or more)	% of population		8	10	22

Source: OECD.

The data show that the world population will change significantly in the next 30-50 years. First, population growth should slow from 1.28% in 2000 to 0.37% in 2050. Second, on average, people will be older. Population ageing will be reflected in an increase in the global median age, from 26 years in 2000 to 38 years in 2050. In addition, the share of children in the total population will decrease, whereas that of older persons will increase. It is expected that in 2050 more people will be over 60 (22%) than under 15 (20%).

All the population growth will take place in developing countries, thus dramatically changing the geographical distribution of population. In 2050 only 13% of the world population will live in OECD countries, compared to 20% today. Also, as migration from rural to urban areas continues, the global urban population will almost double between now and 2050, from 2.87 billion to 5.43 billion. Hence, population growth will be most evident in the cities of the developing world.

  - Population may remain stable in the West.
  - It will decline in absolute terms in Russia and South Africa, Japan, Italy and Germany.
- *Changes in age composition:*
  - Rapid ageing will continue in the West and increasingly strain welfare systems.
  - The demographic transition in the South may lead to high unemployment and instability in the least developed countries.

- The average age will rise worldwide, and ageing will be particularly rapid in countries such as Russia and China.

- *Change in geographical distribution:*
  - National migration (the urbanisation process) will require massive investments in infrastructure.
  - International migration, including illegal migration, will be a source of tension, both in Western countries and between adjacent states in the South.

Social change

- *Cultural globalisation:*
  - New influences on most societies will largely come from external sources rather than from internal developments, both in the West and elsewhere. Major factors are a more multicultural society, mass media and mass travel.
  - Traditional societies will be particularly affected and subject to intense internal conflicts and identity crises.
  - Resistance to change and retrenchment are likely to be strong in the more conservative societies. This could lead to more frequent bouts of fundamentalism.
- *Religion:*
  - The importance of institutional religion may evolve.
  - The erosion of traditional religion may generate a fundamentalist reaction.
  - Inter-faith dialogue may expand.
- *Deepening of current social trends in Western society:*
  - Society will become more secular and materialism will probably increase, owing to scientific developments and rising standards of living.
  - The "religious" divide between the United States and Europe may increase.
  - Relativism and pragmatism are likely to gain ground. With the decline of religion and ideologies, the belief that truth is not absolute but relative, *i.e.* dependent on context, is likely to become more widespread.
  - Increased individualism will be reflected in a decline in the role of the extended family, reduced respect for established authority and an increase in "pick and mix" lifestyles and "benevolent disinterest" regarding choices made by others.
  - Multiple social identities may emerge so that individuals assume different identities (*e.g.* local, national, European) depending on the cause or issue at hand. National identity will, however, maintain its significance.

Economic

- *Growing importance of the market economy, as reflected in:*
  - Further progress in former communist countries.
  - An increasing role for the developing world, as appropriate institutions, laws and regulations are gradually put in place.
- *The role of the market will be fostered by a continuation of the globalisation process through:*
  - An increase in the movement of goods and services.
  - Increased movements of capital.
  - Greater labour mobility.
- *However, setbacks may occur:*
  - Protest movement may slow the process.
  - Protectionism may re-emerge following a major recession or a deterioration of international relations.
  - Major OECD countries may renounce their commitment to free trade.
- *If the globalisation process continues, growth may be sustained (rise of per capita income of perhaps 2% a year on average globally):*
  - Consumer demand may rise, notably among the growing middle class in Asia.
  - Freer markets may foster an efficient use of resources.
  - New technologies will spur productivity growth and create new markets.
- *However, growth will be neither smooth nor equally distributed:*
  - Economic cycles will remain prevalent.
  - The developing world will grow twice as fast as the developed world, but disparities in per capita income between the North and the South will remain huge and growth will be unevenly distributed in the South.
- *Foreign direct investment (FDI) will play an increasingly important role in development in the South as government aid declines:*
  - The pattern of development will be uneven, as FDI will be concentrated in a small number of dynamic economies with large domestic markets.
  - There will be greater pressure on other countries to open up their market and to abide by international standards.
- *Global poverty will decline in relative, and perhaps also in absolute, terms, but it will increasingly be concentrated in certain regions, notably the Near East and Africa.*
- *Among G7 countries, the United States is likely to be the most dynamic economy. The EU is likely to enhance its position as the world's largest economy, notably through a series of enlargements that will both add to its population and induce*

rapid growth in "catching up" regions. There are major uncertainties regarding the future of Japan.

- *If China sustains its exceptional growth over the period, it could overcome the EU as the world's second largest economy as early as 2015 and may reach parity with the United States by 2030.*
- *Future economic risks are significant:*
  - Globalisation will further limit government economic policy and severely penalise poor governance. The poorer states will be the most vulnerable.
  - Income inequalities in developing countries are likely to increase, as only a fringe of the population will be in a position to benefit from increased prosperity, at least in the early stages of development. This could be a source of serious conflicts between the elite and the rest of society and between rich and poor regions.
  - Economic shocks may have devastating effects on some countries or regions as crises can spread quickly in an increasingly interdependent world and as there will be less room for error in domestic policy owing to more mobile capital and more transparent information on national policy and performance.
  - Discontent may be widespread in countries experiencing slow growth and a bulge in the working age population. This may result in increased militancy and increased migration to the West.
  - Economic growth will also require greater use of resources and growing environmental pressures.

Energy and environmental trends and factors

The environmental outlook is poor. As greenhouse gas (GHG) emissions more than double over the next 30 years, an increase in temperature appears inevitable; this will cause a noticeable rise in sea levels, more unstable weather conditions and a shift in endemic and infectious diseases. Implementing appropriate GHG abatement policies at international level will prove difficult because of economies' high dependence on fossil fuels and because of the externalities involved. Higher local levels of pollution are also expected in large parts of the developing world, together with further deforestation, soil erosion and reduced biodiversity. On the other hand, OECD countries and a number of middle-income countries should give greater attention to environmental issues.

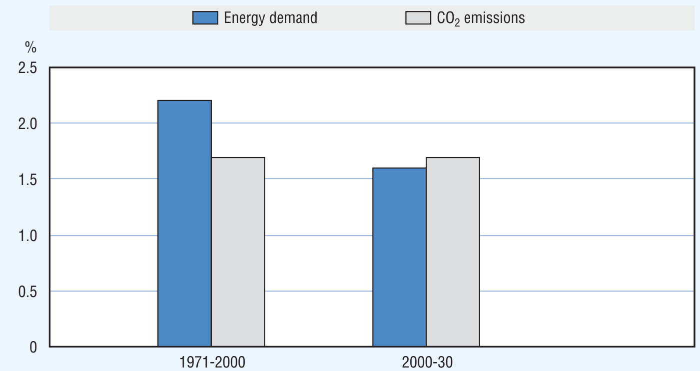
On the energy front, fossil fuels are expected to continue to dominate consumption. Oil will remain the most important fuel. While oil reserves should remain sufficient to meet demand over the period, major investments will be required for exploration, extraction and transport. Moreover, the price

of oil may become more volatile, as conventional energy reserves decrease and are more concentrated in the Persian Gulf area. Gas is likely to be the fossil fuel of choice because of its relatively low carbon content; hence demand for gas is expected to rise rapidly, while demand for carbon-intensive coal should increase more slowly. Nuclear power will remain contentious despite its clear advantages from the perspective of GHG emissions. Greater effort will be made to promote the use of renewables, but their overall share of energy consumed will remain very low, as it will prove extremely difficult to steer the energy system away from fossil fuels.

Environment

- *Global warming:*
  - The majority view (Intergovernmental Panel on Climate Change – IPCC) is that global temperatures may rise by 0.4 to 0.8 degrees by 2030.

Box B.6. **World energy demand and CO_2 emissions**
Average annual growth rates



Source: IEA, *World Energy Outlook 2002.*

The relationship between growth in total carbon dioxide (CO_2) emissions and growth in primary energy demand is expected to reverse over the next 30 years when compared to 1971-2000. While the annual average growth rate of CO_2 emissions should remain the same (1.8%) as in 1971-2000, the average growth rate in primary energy demand should decline from around 2.2% in the earlier period to 1.8% in the 2000-30 period

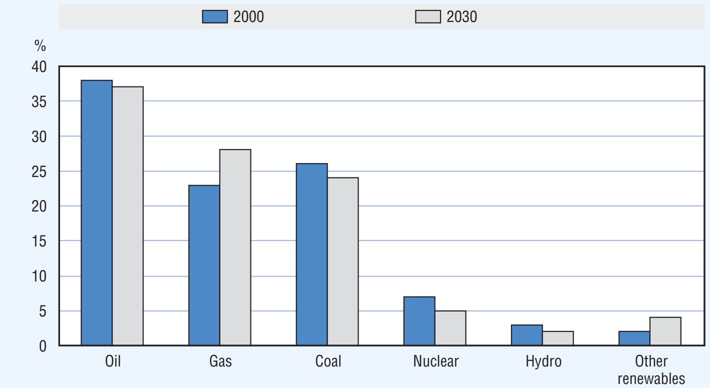
- The minority view is that a new equilibrium will be found, with the seas and forests absorbing the extra CO_2, or that other factors are at work (variation in the Earth's orbit, variation in the Sun's output).

- *Impact of global warming (majority view):*
  - A rise of 10 cm in sea level by 2030 will cause increased flooding in some countries (*e.g.* Bangladesh) and salination of watertables and agricultural land.
  - Grainbelt regions may shift northwards and the size of deserts may increase.
  - Countries highly dependent on agriculture may suffer severely.
  - Climates may become more unstable (more droughts, forest fires and floods) putting increasing demand on humanitarian assistance and disaster relief from abroad.
  - Exposure to certain endemic and infectious diseases may shift.
- *Finding appropriate solutions will be difficult:*
  - High dependence on fossil fuels is likely to persist.
  - A truly global international agreement is required to address the problem effectively.
  - It is hard to "sell" the need to make painful adjustments now for possible future benefits.
- Ozone depletion can result in increased frequency of skin cancers and have adverse effects on flora and fauna.
- *Local environmental damage will increase in the developing world:*
  - Pollution will increase as polluting industries move south and as the urbanisation process continues.
  - Deforestation and soil erosion will reduce biodiversity and agricultural fertility.

Energy

- *The demand for energy is likely to double over the next 30 years:*
  - Most of the increase will take place in the developing world, notably in China and India.
- *No major breakthrough is expected in primary energy technology.*
  - Increasing demand for primary energy will be met by existing sources of supply.
  - Oil will remain the leader, fulfilling about 40% of primary energy demand.

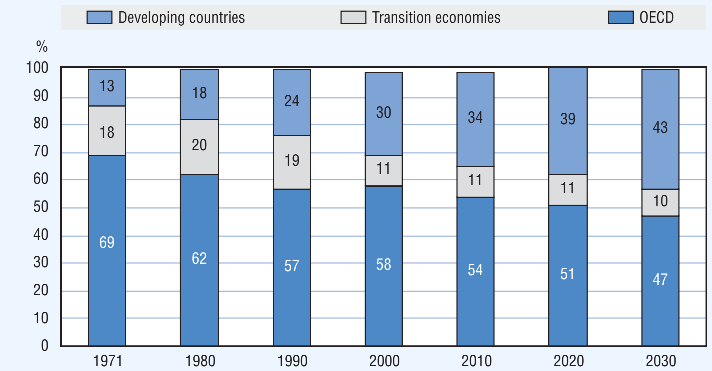
Box B.7. **World primary energy demand**



Source: IEA, *World Energy Outlook 2002*.

According to International Energy Agency (IEA) estimates, oil will remain the most important energy source for the next 30 years, with a practically unchanged share of global demand at 37-38%. Gas will overcome coal as thesecond-largest energy source, and nuclear and hydro energy will decline. Other renewable energy sources will double their share of global demand but will remain insignificant, meeting only 4% of world primary energy demand in 2030.

Regional shares



Source: IEA, *World Energy Outlook 2002*.

Box B.7. World primary energy demand *(cont.)*

The pattern of regional primary energy demand is likely to change. Although demand in developed countries will increase, their share in global demand will decline from 58% in 2000 to 47% in 2030 owing to an explosion in demand from emerging economies, mainly in Asia, whose share in world demand will increase by almost 50%, from 30% in 2000 to 43% in 2030. The share of the transition economies should remain largely unchanged.

The increase in energy demand creates new pressures on the energy supply and on the environment.

  - Oil extraction will become more difficult and large investments will be needed for exploration, exploitation and transport.
  - Oil prices may become more volatile after 2015.
  - Growing dependence on the Middle East and the Caspian Sea regions will give these countries increased geostrategic leverage. However, according to the International Energy Agency (IEA), the Persian Gulf region will increase its share of world oil production only to 36% in 2030, from 33% in 2003.
- *The share of natural gas will increase:*
  - Reserves are adequate but not always easy to tap.
  - Price is likely to be less volatile than that of oil, given greater relative reserves and weaker controls on the volume of supplies.
- *Pipelines and tankers will remain the main transport mode.*
- *Consumption of coal is not expected to grow as fast as in the past, but it may rise again later in the century as other fossil fuels are exhausted.*
- *Nuclear power will remain contentious. It may spread to some new states, notably if safety improves, while it will decline in others.*
- *The use of renewable energy will expand, but will remain marginal overall.*

Technology trends and factors

In future, as private R&D increases, innovation is expected to become more market-driven. Greater emphasis may thus be placed on applied research and the rate of obsolescence may accelerate. R&D will also become more internationalised. In this context, issues related to intellectual property and export controls will have greater prominence on the international policy agenda.

In a favourable institutional and political context, major innovations in a broad range of technologies – notably information and communications technologies (ICT), biotechnology and nanotechnology – may fuel sustained growth for decades to come. ICT should remain a major source of productivity gains, while biotechnology is likely to offer unprecedented control over ageing and reproductive processes as well as major advances in the prevention and treatment of disease. It will also have important applications in agriculture and pollution reduction. Progress in nanotechnology could pave the way, among other things, for the development of new materials, more powerful computing, more sophisticated networks, new sensors for detection at the molecular level, stealth materials and micro-vehicles. Progress is also expected in the development of smart materials and in power generation, notably fuel cells that may find widespread application in the transport and energy-generation sectors. However, carbon sequestration technologies are not expected to come on stream before the end of the period.

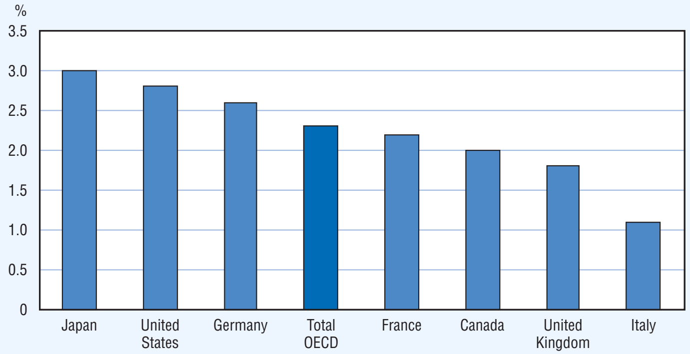
However, technology also has a darker side. First, certain fields of inquiry (*e.g.* cloning) raise major ethical issues. Moreover, advances in biotechnology may lead to the development of weapons that could easily fall into the wrong hands. While countermeasures would also be found, the risk of large-scale loss of life would be high. Progress in ICT and nanotechnology may also lead to the development of WME, and the widespread application of some these technologies may result in a complete loss of privacy. It is possible that issues relating to the negative side effects of technology will trigger a strong "anti-science" backlash in large segments of the population as well as requests for much tighter controls on R&D activities worldwide.

General trends

- *The future geography of R&D:*
  - Up to 2030 OECD countries will continue to dominate innovation in science and technology.
  - The United States should remain the main R&D actor at least until 2020.
  - Europe, China and India may challenge the United States in niche areas.
- *Intellectual property.* Protection of intellectual property will take on greater importance. Given an increased volume of research, ease of information sharing and less tight controls on how research takes place, the challenge will be to do so effectively.
- *Regulatory control.* Attempts will be made to regulate the transfer of technologies with potential military use. This is unlikely to prevent technology leakage to state and non-state actors.

Box B.8. **Gross domestic R&D expenditure**

Percentage of GDP



Source: OECD, *Main Science and Technology Indicators*, November 2002.

Most of the world's R&D activities are conducted in OECD countries. Within the G7, Japan, the United States and Germany are the most technology-oriented.

- *International scope.* Research will increasingly be conducted on an international scale. Except for the United States, no country will be in a position to remain at the leading edge of all the technologies it considers essential. This will further complicate the protection of intellectual property and the effectiveness of regulatory controls on technology transfer.
- *Growing private funding.* The trend towards greater private funding of research in OECD countries will continue.
- *Market-led innovation.* Most innovations are likely to originate in the private rather than the public sector. As a consequence, there may be more applied than basic research. However, major fundamental breakthroughs are expected, notably in biotechnology-related areas.
- *Technology leaps.* Developing countries may be able to take technology leaps by importing mature technologies.
- *System integration.* The integration of several technologies is likely to provide the highest payoffs. Therefore, techniques for applying technology to desired ends will be as important as technology itself.
- *Technology gap.* Without the appropriate infrastructure and education, the gap between those who are technology-competent and those who are not may increase.

Technology-specific trends

ICT

Box B.9. **Goals of the International Technology Roadmap for Semiconductors for technological progress**

	2002	2005	2010	2016
DRAM half-pitch[1] (nanometres)	115	80	45	22
DRAM memory size (mega or gigabits)	512 M	2 G	8 G	64 G
DRAM cost/bit (micro-cents)	5.4	1.9	0.34	0.042
Microprocessor physical gate length[2] (nanometres)	53	32	18	9
Microprocessor speeds (MHz)	2 317	5 173	11 511	28 751

DRAM = dynamic read-only memory.

1. Half pitch refers to the space between metal lines – the smaller the space the more cells in a given area.
2. The gate length refers to the length of the "switches" on a chip – the shorter the gate, the faster the chip.

Source: Bouchard, R. (2003), "Technology Development and the Future of the Space Sector", OECD Working Paper.

The International Technology Roadmap for Semiconductors (ITRS) team has set some rather ambitious goals for the semiconductor industry, including a more than hundredfold decline in the cost of DRAM over the 2002-16 period.

- *ICT will remain a major engine of growth for the world economy*
  - Physical limitations on the current CMOS [complementary metal oxide semiconductor] generation of chips will be overcome, as new technologies come on stream.
  - Consumer demand for increasingly powerful chips may decline, as much of the demand may be satisfied by "value transistors", which are cheaper. This could affect the pace of further technological development.
  - Software may play a role, but new software developments are highly unpredictable.
- *On the information technology (IT) front*, a number of disruptive technologies, such as evolvable hardware (EHW), microelectromechanical systems (MEMS), and quantum computing may come on stream or make rapid progress.

- *New network technologies may emerge (smart antennas, mesh networks,* ad hoc *architectures, ultra-wideband transmission) and lead eventually to an "infrastructureless network" that might challenge legacy operators.*
- *The personal computer (PC) and mobile telephony will gradually converge:*
  - Mobile phones may take over from PCs as the main focus of the IT industry. By 2007 nearly 300 million Europeans may be carrying advanced handsets or "smart phones" (colour screens, music players, support for downloadable games, etc.).

Biotechnology

- *Major advances are expected in controlling the ageing and reproductive processes and in disease prevention, down to the cellular and DNA levels:*
  - Advances in genomics will enable human gene manipulation by 2015.
  - Stem-cell research and germ-line engineering will begin to offer the potential to select desirable characteristics for one's offspring.
  - Regeneration medicine will allow the reprogramming of cells to grow new tissues (*e.g.* grow oneself a new heart or kidney).
- *Life expectancy should continue to increase over the next 30 years, thus potentially reinforcing the trend of ageing populations.*
- *Biotechnology may lead to improved livestock and the development of high-yield genetically modified seeds:*
  - This may contribute to reducing food shortages and alleviate poverty and hunger.
  - It will, however, depend very much on the general public's attitude to genetically modified products.
- *Biotechnology will also have military applications:*
  - Advances in biotechnology will increase the capacity to develop biological weapons by state and non-state actors.
  - Biological weapons will proliferate and become more sophisticated after 2015 and become tuneable in terms of duration, survivability, transmission, lethality, potential resistance to treatment and target specificity.
  - More effective counter-measures will also become available.

Nanotechnology

- *A breakthrough in nanotechnology may occur by 2015:*
  - The total market for nanotechnology products could reach USD 1 trillion by 2015, but full exploitation will certainly require more time.

- *The full potential of nanotechnology is not clearly established but it offers opportunities in numerous domains:*
  - Possible military applications may include the development of improved sensors, stealth materials and autonomous micro-vehicles. However, if nanotechnology continues to be commercially driven, it will be hard to control diffusion and to avoid acquisition by potential enemies.
  - The extension of microtechnology to nanotechnology will lead to sensor detecting at the molecular level, using ever more powerful computer processing and vastly greater memory.
  - Medical applications will be slow to emerge owing to high costs and safety concerns. Major breakthroughs will depend on the level of economic growth.

Other technologies

- *Significant developments are likely in areas such as materials technology and power sources.*
- *Smart materials will have a broad range of applications:*
  - By 2015, the development of smart materials may enable the commercially viable production of clothes that respond to weather conditions, interface with information systems, monitor vital signs, deliver medicines and automatically protect wounds.
  - Other possible applications include personal identification and security systems as well as buildings and vehicles that automatically adjust to the weather.
  - Increases in materials performance for power sources, sensing and actuation may also enable new and more sophisticated classes of robots and remotely guided vehicles, perhaps based on biological models.
  - The integration of these technologies in everyday life will depend more on consumer attitudes than on technological development.
- *Advances in energy technologies may have a major impact from both the energy and the environmental perspective. Progress is expected to be gradual rather than revolutionary:*
  - *Hydrogen:* Hydrogen fuel cells have already shown their promise as a source of electricity (*e.g.* the Apollo programme) and heat for buildings and as a power source for electric vehicles. Their increased use may usher in the dawn of the "hydrogen economy". However, the hydrogen will need to be produced from primary energy sources, whether renewable or not.
  - *Solar power cells:* These will become increasingly efficient and their production costs will decline. Incorporation in new construction will

spread. They are unlikely to be competitive in terms of cost with conventional sources of energy for some time.

- *Bioenergy:* Advances in bioenergy technologies may improve their competitiveness, but the development of bioenergy projects for electricity production will remain fairly costly.
- *Biofuels:* Advances in the production of biofuels may reduce their cost and increase their market share, but progress is likely to be slow.
- *Geothermal energy:* Reduction in the costs of exploration, drilling and geothermal conversion systems should improve its competitiveness.
- *Wind energy:* This technology may become more attractive over the next ten years on the best sites. The intermittence of wind power and the large land requirements will remain a limiting factor.
- *Carbon sequestration:* Such technologies are promising but still costly (at least USD 0.2/kWh). Major investments will be needed to make technological breakthroughs.
- *Fusion:* Since the 1950s, progress in harnessing the energy of nuclear fusion for peaceful use has been slow. ITER, a major international effort in this area, could lead the way to the practical application of fusion power. ITER is expected to produce energy at the level of a small fusion power plant and to address the key technical challenges involved in making fusion a practical energy source.

ANNEX C

Contributing experts

Raymond Bouchard
Drachma Denarius
Applied Futures Research & Strategic Planning
Ottawa, Canada

Alain Dupas
International Consultant
Aerospace
and High Technology Sectors
Paris, France

Michel Fouquin
Deputy Director, CEPII
Associate Professor
University of Paris I
France

Henry R. Hertzfeld
Senior Research Staff Scientist
Space Policy Institute
Center for International Science and Technology Policy
George Washington University
Washington, DC, United States

Thomas Kane
Department of Politics
and International Studies
University of Hull
England

Molly Macauley
Senior Fellow
Energy
and Natural Resources Division
Director, Academic Programs,
Resources for the Future
Washington, DC, United States

Matthew Mowthorpe
Department of Politics
and International Studies
University of Hull
England

Walter Peeters
Space Business & Management
International Space University
Strasbourg, France

ANNEX D

Members of the Steering Group

David Abelson
Deputy Vice President
International
Lockheed Martin Missiles
and Space Operations
United States

Giuseppe Aridon
SVP Corporate Development
Alenia Spazio s.p.a.
Italy

Josef Aschbacher
Programme Co-ordinator
Directorate of Earth Observation
Programmes
European Space Agency

Ulrich Beck
Head of Business Development
Astrium Space Infrastructure
Germany

Seta Boroyan
Programme Co-ordinator,
Space Technologies
Commission for Technology
and Innovation (CTI)
Federal Office for Professional
Education and Technology (OPET)
Switzerland

Jean-Marc Chouinard
Chef,
Bureau de la commercialisation,
Technologies spatiales
Agence spatiale canadienne
Canada

Bill Cowley
Director
Institute for Telecommunications
Research (ITR)
University of South Australia
Australia

Pierre Decker
Conseiller de Gouvernement
1re classe
Ministère de la Culture,
de l'Enseignement supérieur
et de la Recherche
Luxembourg

Patrick Eymar
Vice President, Futures Projects,
Launchers Directorate
EADS Space Transportation
France

Paula Freedman
Director of Space Applications
& Transportation
British National Space Centre
United Kingdom

Agnès Grandjean
Chargée de mission auprès
du service des recherches
et applications spatiales
Services Fédéraux
des Affaires Scientifiques,
Techniques et Culturelles
Belgium

Timothy Howell
Principal Administrator
DG Research
European Commission

Roel R. R. Huijsman-Rubingh
Project Director
Ministry of Health, Welfare and Sport
The Netherlands

Chin-Young Hwang
Head, Department of Policy Studies
and International Relations
Korea Aerospace Research Institute
Korea

Andrea Kleinsasser
Manager
Space Research and International
Technology Affairs
Federal Ministry for Transport,
Innovation and Technology
Austria

Karl-Heinz Kreuzberg
Head of Strategy Department
Directorate of Strategy and External
Relations
European Space Agency

Christine Leurquin
Manager, European Programmes
SES Global
Belgium

Leon Noorlander
Policy Advisor
Market & Innovation Department
Directorate-General for Innovation
The Netherlands Ministry
of Economic Affairs
The Netherlands

Ian Press
Director, Data Acquisition Division
Canada Centre for Remote Sensing
Ministry of Natural Resources
Canada

Marcello Ricotilli
Director, Space Program
Telespazio
Italy

Jostein Ronneberg
Director
of Application Development
Norwegian Space Center
Norway

Timothy Stryker
Chief, Satellite Activities Branch,
International
and Interagency Affairs
NOAA Satellite and Information
Services
US Department of Commerce
United States

Per Tegnér
Chairman and Director General
Swedish National Space Board
Sweden

Luca Tonini
Strategy and Scenarios
Alenia Spazio SpA
Italy

Didier Vassaux
Directeur adjoint, Stratégie
et Prospective
Centre National d'Études Spatiales
(CNES)
France

Frederik Von Dewall
General Manager
and Chief Economist
ING Bank
The Netherlands

Monique Wagner
Chief of Space Department
Federal Office of Scientific
and Cultural Affairs
Belgium

Jon Wakeling
Office of the BT Group Technology
Officer
British Telecom
United Kingdom

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Acronyms

ABL	Airborne laser
ABM	Anti-ballistic missile
ABT	Agreement on Basic Telecommunications (WTO 97)
ADSL	Asymmetric digital subscriber line
AI	Artificial intelligence
ASAT	Anti-satellite system
ASEAN	Association of Southeast Asian Nations
ATM	Air traffic management
BERD	Business enterprise R&D
CEV	Crew exploratory vehicle
CIS	Commonwealth of Independent States
CO_2	Carbon dioxide
COS	Commercial observation satellite
CSOC	Consolidated Space Operations Contract
DARPA	Defense Advanced Research Projects Agency
DBS	Direct broadcast satellite
DoC	Department of Commerce (US)
DoD	Department of Defense (US)
DoS	Department of State (US)
DHS	Department of Homeland Security (US)
DTH	Direct-to-home
DTM	Digital terrain mapping
EADS	European Aeronautic Defence and Space Company
EELV	Evolved expendable launch vehicle
EGAS	European Guaranteed Access to Space
EHW	Evolvable hardware
ELV	Expendable launch vehicle
EO	Earth observation
EPO	European Patent Office
ERS	Energy relay satellite
ESA	European Space Agency
ESDP	European Security and Defence Policy
FAO	Food and Agriculture Organisation of the United Nations
FCC	Federal Communications Commission (US)

FDI	Foreign direct investment
GaAs	Gallium arsenide
GBAORD	Government budget allocations or outlays by socio-economic objective
GDP	Gross domestic product
GEO	Geostationary Earth orbit
GHG	Greenhouse gases
GIS	Geographic information systems
GMES	Global Monitoring for Environment and Security
GNSS	Global navigation satellite systems
GPS	Global Positioning System
GTO	Geostationary transfer orbit
GW	Gigawatt
HALE	High altitude long endurance
HCV	Hypersonic cruise vehicle
HS	Harmonized System (World Customs Organization)
IC3	Intelligence, communications, command and control
ICT	Information and communication technologies
IEA	International Energy Agency
IFP	International Futures Project (OECD)
IGO	Inter-governmental organisations
IGS	Information gathering satellite (Japan)
IHS	Intelligent highway systems
ILO	International Labour Organisation
ILS	International Launch Services (US-Russia)
IPCC	Intergovernmental Panel on Climate Change
IRSO	Indian Research and Space Organisation
ISA	International Space Agency
ISIC	International Standard Industrial Classification
ISS	International Space Station
ITER	International project on nuclear fusion
ITRS	International Technology Roadmap for Semiconductors
ITU	International Telecommunications Union
JAXA	Japan Aerospace and Exploratory Agency
JEITA	Japan Electronics & Information Technology Industry Association
JPL	Jet Propulsion Laboratory
KSIA	Korean Semiconductor Industry Association
kW	Kilowatt
LBS	Location-based services
LEO	Low Earth orbit
MEMS	Micro-electromechanical systems
MEO	Medium Earth orbit
MHD	Magneto hydrodynamic

MIPS	Million instructions per second
MNE	Multinational enterprise
NACE	Statistical Classification of Economic Activities in the European Community
NAFTA	North American Free Trade Agreement
NAICS	North American Industry Classification
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NGA	National Geospatial-Intelligence Agency (US)
NGO	Non-governmental organisation
NRO	National Reconnaissance Office (US)
OBP	Onboard processing
OSP	Orbital space plane
PC	Personal computer
PFI	Private finance initiative
PPP	Public-private partnership
R&D	Research and development
RASA	Russian Aviation & Space Agency
RF	Radio frequency
RFID	Radio frequency identification
RKA	Russian Space Agency
RLV	Reusable launch vehicle
SAC	Space Activities Commission (Japan)
SBL	Space-based laser
SLI	Space Launch Initiative
SLV	Small launch vehicle
SPS	Solar power satellite
SS/L	Space Systems/Loral
STAS	Space Transportation Architecture Study
TDF	TéléDiffusion de France
TSTO	Two stages to orbit
TV	Television
UNESCO	United Nations Educational, Scientific and Cultural Organization
USPTO	United States Patent & Trademark Office
UV	Unmanned vehicle
WHO	World Health Organisation
WME	Weapons of mass effect
WPT	Wireless power transmission
WTO	World Trade Organization
WTTC	World Travel & Tourism Council

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