Space Policy 27 (2011) 194–201

Contents lists available at SciVerse ScienceDirect

Space Policy

journal homepage: www.elsevier.com/locate/spacepol

Earth observation and the public good

Ray Harris*, Lewis Miller

Department of Geography, University College London, Gower St, London WC1E 6BT, UK

ARTICLE INFO

Article history:
Received 1 June 2011
Accepted 15 August 2011
Available online 2 October 2011

ABSTRACT

The term 'public good' is often used in satellite Earth observation to indicate that Earth observation data are of value or interest to the public. In fact, the term 'public good' has a more specific meaning, originating in the discipline of Economics, which carries with it a set of assumptions and implications about how markets operate. In this context a public good has two main characteristics: non-rivalry and non-excludability. In their most common digital format, Earth observation data can appear to be both non-rivalrous and non-excludable. However, it is not the digital medium itself which controls the 'publicness' of a good but the conditions of access to that good. This paper explores the meaning of the concept of public goods in an Earth observation context by, first, examining public good theory and related concepts of categories of goods and, second, applying the concepts to nine Earth observation missions, programmes and data.

1. Introduction

The positive effects of Earth observation in scientific, legal, environmental, humanitarian, security and economic sectors are not fully captured by existing methods of representing value to society, yet the term 'public good' is often used in satellite Earth observation as both a rallying cry and a simple categorisation. Earth observation data are often described as being useful for a long list of applications that are generally of value for the public (pollution detection, forestry management, agricultural monitoring, etc). In this context the term 'public good' is misused, as it has a more specific meaning originating in the discipline of Economics. The true definition carries with it a set of assumptions and implications about how markets operate [1,2]. A public good has two main characteristics: non-rivalry and non-excludability [3]. Non-rivalry means that the consumption of the good by one user does not diminish the capability of another user to use the good: in practical terms, it is impossible for one user to consume a good in a way that reduces the benefit for another user. Non-excludability means that no user of a good can exclude another user from using the same good, meaning that it should be impossible to regulate or limit access to the good. Commonly cited non-rivalrous and non-excludable resources include clean air and public street lighting. It is difficult to assign ownership to true public goods, which complicates buying, selling and managing them. By contrast, a seat on a public bus is not a public good, as the consumption of the good, i.e. someone sitting on it, excludes another person from sitting on the seat and consuming the good. As the good is consumed (by the seat being occupied), other potential consumers are excluded from sitting on the seat. Consumers within the market are rivals, competing for seats on the bus.

Because Earth observation data are now normally in digital form they can appear to be both non-rivalrous and non-excludable: numerous copies of the digital data can easily be made with no loss of quality, and users can download much Earth observation data over the internet. Those who want the data appear to be free to access them. However, as is apparent from the music and film industries, with their CDs, DVDs and downloads, it is not the digital medium itself which controls whether a good is a public good or not but the conditions of access to that good, i.e. the data policy. The term 'public good' has a powerful legacy in Economics [1,2] and deserves to be used correctly in Earth observation rather than in a general and usually mistaken sense. The purpose of this paper is to explore the meaning of the concept of a public good and other categories of goods in an Earth observation context. In Section 2 of the paper we examine public good theory and related concepts of categories of goods so that a coordinate system into which all goods can be placed can be defined. In Section 3 of the paper we then apply the concepts of public goods and other categories of goods to Earth observation missions, programmes and data.

The Global Earth Observation System of Systems (GEOSS) is probably the leading illustration of the mistaken use of the public good concept in Earth observation. GEOSS has agreed a set of three data sharing principles, as follows [4].

* Corresponding author.
E-mail address: ray.harris@ucl.ac.uk (R. Harris).

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doi:10.1016/j.spacepol.2011.09.010

1. There will be full and open exchange of data, metadata and products shared within GEOSS, recognizing relevant international instruments and national policies and legislation.
2. All shared data, metadata and products will be made available with minimum time delay and at minimum cost.
3. All shared data, metadata and products being free of charge or no more than cost of reproduction will be encouraged for research and education.

These three principles speak of full and open exchange of data, yet these positive principles are surrounded by uncertain terms and poorly defined variables, which make the principles unremarkable and difficult to enforce. Recognition of national legislation, the lack of definition of minimum time delay, minimum cost and the meaning of the cost of reproduction all pose implementation challenges (see [5]). It is not difficult to argue that, because of the exceptions, these principles close off nothing, despite the clear signals of the opening words of "full and open exchange". Having agreed an uncertain set of data sharing principles, GEOSS then developed an implementation plan for the principles [4], just as ESA did with its Envisat data policy [6]. There are six guidelines in the GEOSS implementation plan of which item four is specific about the public good.

> The pricing of GEOSS data, metadata and products should be based on the premise that the data and information within GEOSS is a *public good* for public-interest use in the nine societal benefit areas. GEO, together with its GEOSS data providers, should work to set standards for the full and open exchange of data *based on this premise*, with the only allowable cost for data being either that of reproduction and distribution, or the marginal cost of fulfilling the user request (our emphases in italics) [4].

Are the data and information in GEOSS really non-rivalrous and non-excludable public goods? Has GEOSS considered what the term public good means before claiming it to be the premise on which to build full and open exchange of data? Other subject areas (such as law and environmental economics) have sought to define goods very precisely, especially where value and positive contributions are not entirely captured by markets [7]. Is this misinterpretation of terminology, encoded in an implementation of a data policy, helpful for Earth observation or should the Earth observation sector seek greater precision of terminology too?

An exploration of the use of the term *public good* and related terms is not just a question of semantics, it has direct policy relevance in both the public sector and the private sector. Without explicit measures of the value of Earth observation data [8], it is difficult for governments to evaluate and subsequently test the right level of investment in Earth observation. This important value argument depends on the starting point of the potential contribution of Earth observation data to the public good and to other sectors of the economy. In the private sector investment decisions need to take account of the very different economic implications of the claims for Earth observation data to be regarded as a public good or as other forms of goods: the debate so far has tended to polarise as public/private goods while in reality there are many intermediate forms of goods that provide value to all the actors in the value chain of Earth observation.

The general aspiration to create activities that have wide value for the public does have a long and honourable tradition. The principle of utilitarianism is a famous legacy of the philosopher Jeremy Bentham (1748–1832) who recommended that society should act so as to produce the greatest good for the greatest number [9], a maxim that Earth observation unconsciously seems to follow and that GEOSS consciously follows. The political economists John Stuart Mill (1806–1873) and Henry Sidgwick (1838–1900) both explored the proper role of government in providing goods that are used by the general public [10].

2. Public good theory and related models

2.1. Public and private goods

The origin of public good theory can be traced to Paul A Samuelson, who developed a theory for public goods that has a simple message: a public good is a good (data, information or service in Earth observation terms) that, once produced for some consumers can be consumed by additional consumers at no additional cost [1]. The message carries within it the two main characteristics of a public good, namely non-rivalry and non-excludability. While the message is simple, the term public good is often treated ambiguously or inconsistently, not least because it includes the word 'public' which suggests or implies to many a role for the public sector in the production of a public good [11,12]. This is the case with the GEOSS interpretation.

In contrast to public goods, private goods are rivalrous and exhibit consumption scarcity because the consumption or use of the good diminishes or removes the availability of the good to others. A private good must be excludable to ensure that prices and other exclusion mechanisms effectively control the number of beneficiaries, and property rights must be applied to establish legitimate ownership. If non-paying users cannot be excluded from benefits then the market for the good fails as a result of free-riding [3].

The distinction between public goods and private goods is not necessarily black and white. When the public–private status or degree of 'publicness' of a good is unknown, as is often the case with Earth observation, then the assumptions underlying market theory and the operation of markets can be broken. Elements of non-rivalry and non-excludability cause market inefficiencies and lead to market failures, which in turn suggests a role for government before a market matures. Policy development and legislation of markets is hampered by poorly defined value characteristics. Significant components of Earth observation data value lie outside normal markets, which is unfortunate as these non-market benefit streams are typically excluded from traditional accounting. In particular, public good characteristics are poorly represented in valuation strategies [13], weakening the advocating leverage of Earth observation [8]. Benefits which are not explicitly captured by traditional market economics (positive non-market externalities) constitute hidden markets, and their exclusion leads to the undervaluing of Earth observation, incomplete analysis and insufficient consideration in policy formulation [14].

All these uncertainties suggest that there are degrees of publicness in both public and private goods, a publicness that can be fruitfully categorised through the assessment of the two core characteristics of non-rivalry and non-excludability combined with an assessment of the extent to which external, non-market value should be included.

2.2. Public goods and alternative models

Fig. 1 is a diagram showing the two main axes of rivalry and excludability, both ranging qualitatively from low to high. On these two axes are plotted points and zones to represent seven categories of goods. The categories include public goods, private goods and goods with varying elements of publicness and privateness [7]. These seven categories of goods are identified and summarised in Table 1 and discussed below. In Section 3 of this paper these categories or models are applied to the case of Earth observation.

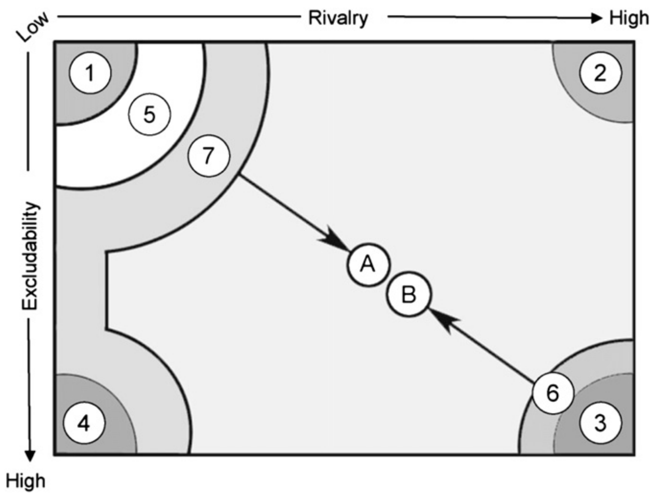

Fig. 1. The landscape of goods discussed in this paper mapped on the two axes of rivalry and excludability. Each of the two axes range from low to high, i.e. low to high excludability of a good and low to high rivalry of a good. The seven numbers on the map correspond to the seven types of goods listed in Table 1 (public good, common pool good, merit good, etc). Vector A illustrates value-adding investment in a good with its associated increase in the rights of ownership (see the information goods section of this paper). Vector B illustrates the case where government investment may reduce the full private good rights because of a worthy societal benefit (see the section on orphan drugs scenario in this paper).

2.3. Common pool resources

In Fig. 1 public goods (category one) are naturally characterised as having low rivalry and low excludability, while private goods (category three) at the opposite corner of the diagram naturally exhibit high rivalry and high excludability. When goods have high rivalry and low excludability (category two in Fig. 1) they can be thought of as common pool resources in that they reside in the commons and are accessible to and managed by everyone [3]. Individuals cannot exert property rights and users or consumers collectively own and manage the resources as stakeholders. Because individuals may depend on goods for welfare, the responsibilities and benefits of effective stewardship are shared. Sustainable use of common pool resources is only possible when users or consumers cooperate. If individuals consider only their own returns with no concern for the management of the good, then over-exploitation occurs through the so-called tragedy of the commons [13,15]. An example of a common pool resource is fish populations in international waters: the fish resources are rivalrous but non-excludable. It is necessary to protect fish stocks and enforce quotas in international agreements in order to ensure sustainable exploitation by all.

Table 1
Types of goods and their characteristics shown in Fig. 1.

Label	Type of good	Characteristics
1	Public good	Simultaneously non-excludable and non-rivalrous
2	Common pool good	Non-excludable but rivalrous
3	Private good	Rivalrous and excludable in consumption
4	Club good	Non-rivalrous in consumption but mechanisms exist to exclude consumers
5	Merit good	Low on both rivalry and excludability but with a clear focus on positive externalities
6	Orphan drug scenario	Response to market under-provision
7	Information good	Non-rivalrous but variable in excludability

2.4. Club goods

Goods that are consumed in a non-rivalrous manner but from which consumers can be excluded are known as club goods (category four in Fig. 1). Buchanan refers to a process of extending ownership rights to different groups of people so that only accredited consumers or users are permitted access to the good [16], and he proposed that a theory of clubs or club goods could "move one step closer to closing the awesome Samuelson gap between the purely private and the purely public good" in support of a concept of a continuum of publicness where few qualify as purely private or purely public [17]. Furthermore, Buchanan asserts that few goods can be non-rivalrously enjoyed by groups of infinite size – the original Samuelson condition for pure publicness – yet many goods share elements of publicness in their consumption. When it is possible to determine the membership margin or optimal group size it is favourable to administer the good using a club good model. Several issues in the early club analysis of Buchanan are of burgeoning importance in Earth observation and more widely in the field of digital environmental information. Assessment of the costs of implementing and administering exclusion devices were not addressed until 1991, and questions of digital data as quasi-public goods arose as late as 1994 [18,19].

Two common examples illustrate the club good model. The first is a municipal swimming pool which is run on a not-for-profit basis. It is unlikely that the pool would be constructed for a single swimmer, so the facility is provided only on condition that users join a club to use the pool. A fee structure offsets construction and running costs, and the users accept certain conditions of use including rules. As membership numbers grow the per-swim cost decreases as unchanged or fixed costs are borne by more users. This implies at first that swimmers get better value as the pool has more members, but later over-crowding means that growth is not infinitely sustainable. Club management of a good is a strategy for reducing rivalry, managing the behaviour of consumers and controlling public good exploitation [3]. A second example is a vantage point overlooking a beautiful landscape such as the Grand Canyon in Arizona. A fine vista is a good that is largely public in nature when enjoyed by a few, but an overload of tourists can result in rivalry for the view and a reduction in the value of the good. An entrance fee can introduce excludability and so produce a club good.

2.5. Merit goods

Merit goods (category five in Fig. 1) exhibit low rivalry and low excludability, somewhat similar to public goods but with a different focus. Merit goods are those goods and services which are provided free of charge by governments as they would be under-provided if left to the private sector or to normal market forces. Classic examples of merit goods are education and health care (such as hospitals for the poor). The concept of a merit good was introduced by Richard A Musgrave in the 1950s, and he describes merit goods as those "considered so meritorious that their satisfaction is provided for through the public budget, over and above what is provided for through the market and paid for by private consumers" (quoted in [20]). This definition sounds similar to the commonplace (and incorrect) use of the term public good in Earth observation, but there is one important additional dimension to a merit good beyond a public good: merit goods produce positive externalities, that is there is clear merit which would not otherwise be provided through the private sector. In the examples cited above, a better-educated population will be more creative, more productive and more efficient, while a healthier population will work more effectively and for more hours than an unhealthy population.

Merit goods embody the concept of the greater good: it is normal for governments and not individuals to take responsibility for the greater good, although there are counter-examples such as philanthropists and large-scale funders of biomedical research.

2.6. Orphan drug scenario

One special category of goods in Fig. 1 is the orphan drug scenario (category six) which is relatively high in both rivalry and excludability but with special conditions. The term itself originates in medical research [21], and provides useful contributions in other fields. The term was first used in the early 1980s to reflect the growing need for drugs to treat minority conditions. Ratified in US law in 1983 in the Orphan Drug Act (Public Law 97–414), the principles of the Act enabled spending on research and development of new drugs specifically for conditions where the potential market was small (in the USA fewer than 200 000 affected individuals). Previously it was considered financially disadvantageous to fund research into drugs for minority conditions, leading to increased suffering and a slow pace of development in treatment. The 1983 US Act formalised the acceptance that increased human suffering was the result of under-provision by a market left to decide its own priorities, and led to similar legislation in Japan (1993), Australia (1997) and the European Union (2000).

The orphan drug scenario provides a mechanism for the centrally-funded supply of a good in the face of an uncertain return on investment by the private sector. In the medical case the objective was to reduce human suffering by removing mitigating activities from sales-led environments and making provision for them by using public policy instruments. In Fig. 1 this action is illustrated by vector B: the rivalry and excludability of the category six goods are both reduced by selective government policy support for specific worthy causes.

2.7. Information goods

Information goods and services (category seven in Fig. 1) are characterised by non-rivalry and variable excludability depending on content, data policy and technological limits of usage. Digital information is infinitely reproducible at almost zero marginal cost with perfect quality, and developments in global networks and the internet facilitate low-cost dissemination [22]. Longhorn and Blakemore note, however, that, while the marginal cost and the distribution cost of digital environmental data are low, this should not obscure the fact that environmental data are very expensive to collect, process and maintain [23].

Investment in the value-adding process permits individuals to claim ownership of a good, as illustrated by vector A in Fig. 1, where there is an increase in both rivalry and excludability as a result of investment. Increased excludability can control information user groups and transpose optimal management approaches from information goods to club goods territory. The existence of successful markets for information goods depends on practical excluding devices such as intellectual property rights, patents, copyright and end-user licences.

Many information goods can be effectively managed using strategies from other zones in Fig. 1. The use of excluding devices (such as access keys) to protect revenue causes a shift towards rivalry and private goods. Similar devices that have no financial element lead to a club good regime, although complicated by a lack of crowding and potentially infinite club size. Information goods can be public goods if non-rivalrous and non-excludable, or merit goods if they would be under-consumed and neglected if left to market forces and individual choice. Occasionally information goods may be important but exclusion devices seem unethical. In such cases it is possible to ensure their provision by using management schemes normally applied to orphan drugs scenarios, merit goods or public goods.

The management of information goods usually relies on ‘hard’ or ‘soft’ excludability. Typical approaches to hard exclusion include water-marking of data [24], serial number allocation and licensing. Soft exclusion depends on consumer skills and capacity. It is tempting to claim that internet dissemination is non-discriminatory, but this is only valid if network users can gain practical access. Only qualified users who possess the requisite technological, infrastructural and intellectual keys can benefit [25]. For many potential consumers, especially those in less economically developed countries, barriers to entry into the information goods market are insurmountable because of socioeconomic, income or political factors.

3. Earth observation goods

Having reviewed the seven categories of goods relevant to Earth observation, this paper now examines how different types of Earth observation missions and their data fit on the two axes of rivalry and excludability used in Fig. 1. For this part of the paper nine Earth observation missions, programmes or types of data are plotted onto the two axes of rivalry and excludability and the result is shown in Fig 2. The nine missions or data types are listed in Table 2 and discussed below. It is clear from a first look at Fig. 2 that the publicness or public good nature of Earth observation data is highly variable: one implication of this is that designing general data policies for Earth observation data may well be unrealistic.

3.1. Data type one: meteorological data

With the exception of data less than three hours old from Eumetsat, weather satellite data is available to every interested user, free of charge on an unrestricted basis in line with World Meteorological Office recommendations [26]. Meteorological data greater than 3 h old is perhaps the purest public good of Earth observation data currently available, because of the characteristics of extensive non-excludability and non-rivalry embedded in both the digital format and through data policies. Some technical and socioeconomic exclusions still apply, but as far as possible for the provision of digital information, data is non-excludable. Because users receive a perfect digital duplicate of the original data, meteorological data appear non-rivalrous. Data can be freely provided in this way because costly satellite programmes are funded by the contributions of member states in Europe, and because in the USA taxpayer-funded information is made available inexpensively and as widely as possible [26]. A degree of free-riding is encouraged by administrative bodies because increased use does not incur increased costs, yet leads to societal benefits through merit good

Table 2
The Earth observation mission, programme or types of data categories used in Fig. 2.

Number	Mission, programme or data type	Category of good
1	Meteorological data	Public good
2	Landsat	Public good/merit good
3	NOAA AVHRR	Merit good
4	Envisat ASAR	Quasi-private good
5	SPOT	Quasi-private good
6	Radarsat SAR	Quasi-private good
7	Google Earth	Club good
8	International Charter Space and Major Disasters	Club good
9	Very high resolution sensors	Information good/private good

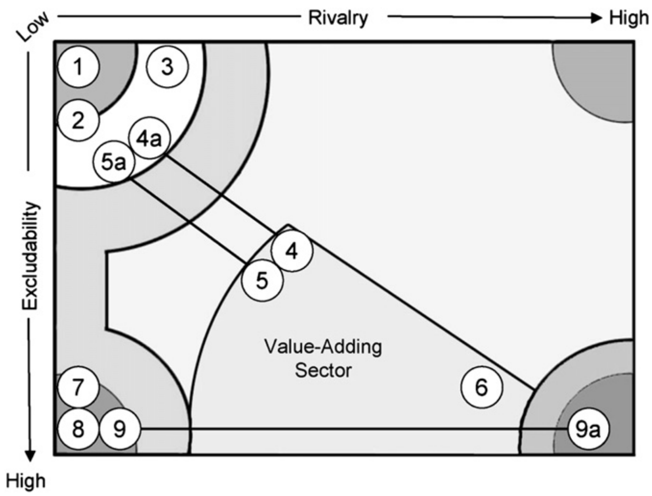

Fig. 2. The general landscape of goods presented in Fig. 1 applied to Earth observation. The diagram uses the same axes of excludability (low to high) and rivalry (low to high) as in Fig. 1. The nine numbers on this figure correspond to the nine Earth observation missions, programmes or types of data listed in the accompanying Table 2 and discussed in the text.

effects [27,28]. Eumetsat is a case in point in the application of its data policy to poor countries: there is no charge for Eumetsat data for official duty use by the national meteorological services of those countries with a gross national income below or equal to US$7878 [29]. The Eumetsat data policy seamlessly administers data as its value components change, depending on currency and the status of the consumer.

3.2. Data type two: Landsat

Landsat data policy reflects the dual objectives of US remote sensing: to distribute federally-collected data free of charge or at minimum cost, and to support the development of a sustainable and varied value-adding sector [19,26]. Operating costs and the burden of supplying the first user are borne by federally funded satellite operators. When first-user governmental activities wholly justify expenditure, subsequent third-party use is of negligible additional cost, so incremental pricing suggests that unenhanced digital data can be provided through on-line channels at almost zero cost [19].

Setting aside issues of soft exclusion, which are difficult to overcome and reside beyond the scope of even federal data policies, the Landsat model aims for non-excludability and the provision of data on a non-discriminatory basis. Referring to Fig. 2 label 2, Landsat excludability appears variable, which reflects costly elements of provision funded by federal budgets. The commercial development of instruments competitive with Landsat transposes the good from public to merit in status under some circumstances.

The extent of rivalry in Landsat data policy is quite clear: it is stipulated that any enhancement or value-adding activity outside the governmental remit is conducted in the private sector and is chargeable commensurate with investment of time and intellectual capital, on a commercial basis [27]. Although there may be apparent rivalry between end-product consumers, this is competition for the time and energy of value-adding personnel, which are excludable and rivalrous resources. Tasking and provision of newly acquired data are not possible with Landsat data and archives are digital and accessible: these elements suggest that Landsat can be considered a non-rivalrous resource supplied by a government fully cognisant of positive externalities, as a merit good in support of the national economy and strategic position.

3.3. Data type three: NOAA AVHRR

In terms of excludability, NOAA AVHRR data are distributed on the same non-discriminatory terms as Landsat products. They can be considered non-excludable for the purposes of categorisation and management. Some AVHRR data exhibit rivalry in consumption. Users who require specific area coverage at 1.1 km HRPT (High Resolution Picture Transmission) ground pixel resolution have two options. If a receiving station is based within the satellite transmission footprint, it may be possible to receive direct-broadcast HRPT data. For guaranteed delivery an application must be made for NOAA to schedule on-board data storage through LAC (Local Area Coverage). NOAA warn that "because recorder space and transmission time must be shared by many requestors, requests must be received at least one month prior to data acquisition period [and] will be considered on a first-come first-served basis" [30]. Because of high LAC coverage demand, the following situations are prioritised.

- national emergencies;
- situations where human life is endangered;
- US strategic requirements;
- commercial requirements;
- scientific investigations and studies;
- other miscellaneous activities.

Limited LAC coverage introduces rivalry based on satellite capacity. This is because AVHRR is a national resource managed by NOAA, representing stakeholders, users and the interests of the funding public. Rivalry, introduced by the need to manage and fairly allocate finite spacecraft resources, alters the position of AVHRR within merit good territory towards common pool status. To use an example, many academics compete for LAC storage and transmission. The scientists must compete for a finite resource which is rivalrous but non-excludable.

The categorisation of AVHRR as a merit good (Fig. 2 label three) represents a change from its original public good status. Technical, political and financial barriers to entry in the late 1970s meant that only governmental satellite provision was then viable. It has been demonstrated that commercial Earth observation business models can succeed, so the continuing provision of AVHRR data fulfils national strategic and human-benefit requirements as positive, non-market externalities, the effects of which justify ongoing expenditure.

3.4. Data type four: Envisat ASAR

In its original form at the launch of Envisat in 2002 the data policy for the Advanced Synthetic Aperture Radar (ASAR) included two categories of use of the data [6]. Category one use covered research and applications development use in support of the mission objectives, including research on long term issues of Earth system science, research and development in preparation for future operational use, certification of receiving stations as part of the ESA functions, and ESA internal use. Category two use covered all other uses which do not fall into category one use, including operational and commercial use. Qualification excludability applied to Category one use goods because users had to comply with restrictions to avoid transgression of Category one boundaries. Although strict usage restrictions seem to impose mandatory club membership on users (commercial or operational use is forbidden) this is not the case because the data policy separates "user" from "use", so even the most public of Envisat Category one applications conform to merit good status.

Activities of users in Category two are more excludable based on price and availability. They reside in the value-added sector of Fig. 2, represented by label four. Individual data products are positioned along the line between Fig. 2 labels 4 and 4a, depending on the category of use, labour-intensiveness of their production and their supply and demand characteristics.

The original Envisat data policy does not address rivalry directly [6], but considers that non-exclusive licensing allows non-discriminatory access, insofar as "nobody in the world can obtain … data alone while restricting its use to anyone else" [5]. This appears to acknowledge the basic non-rivalry of distributed digital goods. For Envisat ASAR it is arguable that radar-based Category two uses are likely to require more detailed expert intervention than optical data, increasing potential rivalry. Processing streams are more complex and technically challenging [31,32]: the greater investment of time and intellectual capital is reflected in the higher price of radar products. If distributors allocate sufficient resources for the processing of this data, rivalry in time-allocation is offset against greater excludability through price because investment in staff must be accounted for. Radar products under Category one use are also more rivalrous than their optical counterparts because greater intellectual and technical requirements increase 'soft' exclusion and reduce the pool of individuals capable of effectively using the data. In real terms 'soft' exclusion is not a major consideration for ASAR because individuals who qualify for Category one use are likely to possess the required technical skills, and Category 2 use-groups include operational and commercial entities capable of overcoming greater price-exclusion to acquire complex data.

In May 2010 ESA changed its data policy for Envisat (and all ESA Earth observation) data [33]. Now all Envisat ASAR data are in Category one and can be thought of as merit goods (see label 3 in Fig. 2).

3.5. Data type five: SPOT

SPOT data initially appear to reside entirely within the zone of private goods, thanks to price-based excludability and rivalry for satellite pointing and subsequent data processing. However, this is not completely the case because an agreement with ESA also provides SPOT data as a merit good (illustrated by Fig. 2 label 5a). ESA and SPOT Image aim to supply 10 000 SPOT products per year for what is in ESA terms Category one use. ESA states that "besides its commercial activities the company [SPOT Image] has a mission to promote the use of satellite images; the agreement with ESA giving easy access to the SPOT data encourages the scientific community to get involved in the space sector" [34]. The offer of SPOT data to ESA consumers may also be a practical illustration in Earth observation of orphan drug scenario provision, whereby the number of consumers in a market cannot sustain commercial provision, at least initially.

3.6. Data type six: Radarsat SAR

The Radarsat-1 satellite programme is administered by the Canadian Space Agency (CSA) in association with US government departments (NASA and NOAA) and Canadian provincial administrations. The data policy shares some elements with Envisat and Landsat approaches, with the addition of cost-recovery mechanisms beyond incremental or marginal pricing. A private company named Radarsat International (RSI) was established following the launch of Radarsat in 1995 under contract to the CSA to process, distribute and market Radarsat data to the user community on a quasi-commercial basis. The objective was to recover operational costs through data sales in the same way as SPOT Image [35]. The CSA licence agreement installed RSI as sole agents, and allowed the company to set market prices and recruit local distributors under exclusive terms. The Radarsat-2 mission is administered as a public-private partnership between CSA and MDA. Brûlé et al. comment that "under agreement with the CSA, MDA will own and operate the satellite …the CSA's investment will be recovered through the supply of imagery to Canadian Government user departments during the lifetime of the mission" [36].

In addition to issues of price-based excludability, Radarsat data is rivalrous because of the wide range of modes, processing levels and satellite tasking options. Fifteen priority levels and seven core products are offered by Radarsat (excluding polarisation options); each is priced according to beam mode, level of processing and urgency of delivery [35, 56]. Price determined by processing level compensates MDA for investment of intellectual capital, but the introduction of rapid-turnaround data for a higher fee introduces formal competition, or rivalry, between consumers. Clearly Radarsat SAR data are private goods that demonstrate both high excludability and high rivalry (Fig. 2 label 6).

3.7. Data type seven: Google Earth

Google Earth is a software and data application that can be downloaded free of charge and permits the exploration and display of geographic information via an internet connection. The data is collated from over 100 sources including aerial imagery, Landsat satellites, commercial remote sensing satellites and NASA. The application allows users to view a global data catalogue which is centrally processed and managed by Google. Third-party copyright watermarks appear on each image and data sets are tiled automatically. No specialist knowledge is required to navigate through images and it is possible, using a simple interface, to superimpose additional information such as terrain, road networks and national borders. Google Earth has been very popular with internet users – the software was downloaded over 100 million times in the first year of availability [37] – and has changed the public face of Earth observation around the world. It is not possible to store, modify or interrogate data presented through Google Earth, and streamed images are JPEG compressed, causing data loss and reduction in quality. The satellite images accessible through Google Earth commonly approximate to true colour, but they are non-transferable and contain no metadata.

It may seem that Google Earth is non-excludable and non-rivalrous as a resource: it is freely distributed over the internet, and consumers cannot compete with each other in its consumption. However, excludability is introduced in the form of a legally-binding licence agreement, some extracts of which are reproduced below [38] (our emphases in italics).

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To use Google Earth, consumers enter into a compulsory agreement with the provider of the good. If the agreement is unacceptable then the provider declines to supply the good. In this way Google Earth is managed as a club good with non-cost membership criteria, shown in Fig. 2 label 7. Excluding devices are used to ensure rule-compliance among users, fair use and to protect the intellectual property of developers and data providers.

3.8. Data type eight: International Charter for Space and Major Disasters

The International Charter for Space and Major Disasters (ICSMD) was launched operationally in 2000 to provide a policy mechanism to supply processed satellite data for the management and mitigation of natural or technological disasters which cause loss of human life or large-scale destruction of property [39,40]. The Charter was ratified at the 1999 UNISPACE III conference in Vienna by three founding agencies and by 2011 comprised 20 participating member organisations [41].

The Charter allows partial relaxation of normal data policies for the purpose of protecting human welfare. For example, derivative data products processed through Charter activations can be shared without restriction. Although Charter activation involves unusual and extensive data distribution, the lost opportunities of sale may be insignificant because applications served are mainly non-market in nature. Humanitarian consumer-groups are often excluded from the normal Earth observation data market because of funding and budgetary constraints [35], as well as significant knowledge gaps and technical shortcomings [42]. The Charter allows commercial satellites with high quality technical capabilities to be employed in situations where markets and revenue streams could not justify their deployment. Although the Charter can be categorised as an overall club good (Fig. 2 label 8), this particular element of ICSMD has much in common with orphan drugs scenario provision.

As with Google Earth, ICSMD image-map products may be symbolic: they are commonly distributed as high-resolution JPEG map-sheet images [39]. The decision to distribute data as downloadable map-sheets maximises accessibility and reduces technical overheads for field-based aid agencies and other humanitarian relief institutions. Merit goods have greater value when shared widely, as is the case for ICSMD products [19]. They are designed to be widely distributed and used by as many interested groups as possible for the reduction of human suffering. One other component of merit goods is their costly generation. Acquiring and processing satellite data requires expertise for which value-adding companies are compensated from ICSMD operating budgets [27,42].

3.9. Data type nine: very high resolution sensors

Excepting exclusive government use for purposes of national security, data policy in very high resolution remote sensing aims for the development of a private sector market for the sustainable commercial provision of a private good (Fig. 2 labels 9 and 9a) [43]. Price-based exclusion is used, and in contrast to previous business models in Earth observation such as SPOT and Radarsat, suppliers set competitive market prices at levels that enable them to remain competitive and profitable and to recover both fixed and variable costs. A need has emerged to differentiate in an increasingly congested market, in terms of timely delivery, responsive tasking or image quality. Commercial products are exclusive because of pricing and licensing and very high resolution satellite data is also extremely rivalrous. Satellite time is limited, and operators must balance the demands of many consumers. Consumers are rivals in the tasking of the sensor and in the subsequent processing and delivery of data to the degree that waiting lists determine the rapidity of data delivery more than orbital passes or environmental conditions. The majority of very high resolution data is provided entirely as a private good, excludable on the basis of price and legally-binding licence agreements and rivalrous in terms of satellite tasking.

4. Conclusions

The term ‘public good’ should not be used for Earth observation data in general because not all Earth observation data, or even the majority of the data, show the twin characteristics of non-rivalry and non-excludability. The term ‘merit good’ is more appropriate for much Earth observation data. Merit goods exhibit low rivalry and low excludability, and at the same time have explicit recognition of the desire for positive externalities. The nine societal benefit areas of GEOSS are examples of positive externalities.

Data policies have so far failed to capture components of value with sufficient precision or in enough depth to support informed management. Such policies have contributed to under-valuation of the sector and conservative estimates of socioeconomic contributions [7,8]. Industry development may have also been inhibited by lack of information for management. Yet progress has been made in some areas: the Envisat data policy and several programmes of humanitarian data provision implicitly acknowledge public good and merit good applications of Earth observation data.

Mapping the degree of ‘publicness’ of a good, in this case Earth observation data, is a novel approach within Earth observation but similar problems have been addressed in other disciplines such as law and environmental accounting. Methodologies to capture value in other fields (e.g [44].) have the potential to contribute to the development of the Earth observation sector and an improved matching of data policies with applications.

Data policy is political. The claim that Earth observation is a public good is a strong albeit implicit political statement. The Earth observation sector will be better served by a more subtle and more differentiated approach to data policy that explicitly recognises its political foundations.

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