

Chapter 19

The Economic Value of Digital Earth



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Abstract In this chapter, we approach the economic value of Digital Earth with a broad definition of economic value, i.e., the measure of benefits from goods or services to an economic agent and the trade-offs the agent makes in view of scarce resources. The concept of Digital Earth has several components: data, models, technology and infrastructure. We focus on Earth Observation (EO) data because this component has been undergoing the most dramatic change since the beginning of this century. We review the available recent studies to assess the value of EO/geospatial/open data and related infrastructures and identify three main sets of approaches focusing on the value of information, the economic approach to the value of EO to the economy from both macro- and microeconomic perspectives, and a third set that aims to maximize value through infrastructure and policy. We conclude that the economic value of Digital Earth critically depends on the perspective: the value for whom, what purpose, and when. This multiplicity is not a bad thing: it acknowledges that Digital Earth is a global concept in which everyone can recognize their viewpoint and collaborate with others to increase the common good.

Keywords Economic value · Social value · Earth observation · Private sector · Public sector

19.1 Introduction: Framing the Issue

Previous chapters of this manual introduced the concept and definitions of Digital Earth (Chap. 1) and the data and technologies that contribute to it (Chaps. 2–12) and focused on the role of Digital Earth in supporting the achievement of sustainable development, particularly the UN Sustainable Development Goals (Chap. 13) linked to climate change (Chap. 14) and disaster risk reduction (Chap. 15). Each of these areas has both social value to present and future generations (Brundtland Commission

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1987) and economic value, i.e., the measure of benefits from goods or services to an economic agent (person, company or organization involved in an economic transaction) and the trade-offs the agent makes in view of scarce resources.¹ Given that each area of application of Digital Earth has both economic and social value and, by definition, this value varies according to different economic agents (the key question: value for whom?), how can we approach the economic value of Digital Earth?

Previous studies have dealt with the economics of issues linked to sustainable development. For example, Pezzey and Tonan (2017) addressed the economics of sustainability, Anand and Sen (2000) addressed human development and economic sustainability, the review by Stern analyzed the economics of climate change (Stern 2007), and Shreve and Kelman (2014) among others, reviewed the cost-benefit analyses of disaster risk reduction. As far as the value of Digital Earth is concerned, a review of the literature is not much help. A query on “the economic value of digital earth” on Google Scholar returns no entries, and a search on the web returns only the table of contents of this manual. A more fruitful approach may be to deconstruct Digital Earth into its constituent components. As indicated in Chap. 1, Digital Earth can be viewed from multiple perspectives; some emphasize the conceptual/representation aspects of Digital Earth (Gore 1999; Goodchild et al. 2012) and the data/information component (Goodchild 2013), others emphasize the information system component (Guo et al. 2009; Guo 2012; Grossner et al. 2008), and others emphasize the multi-disciplinary body of knowledge and theoretical component (Goodchild et al. 2012; Guo et al. 2009). Each of these perspectives could be the subject of an economic analysis, but the one that has received greatest attention of late is data, described as the “new oil or the most valuable resource” of the digital economy (Economist 2017).

The rise of big data has recently been outpacing the growth in computer processing power and is set to speed up even further with the advent of the Internet of Things and billions of devices connected to the internet via 5G networks. For example, between 2002 and 2009, data traffic grew 56-fold, compared with a corresponding 16-fold increase in computing power (largely tracking Moore’s law), as shown in Fig. 19.1 (Short et al. 2011; Kambatla et al. 2014).

The evolution of Digital Earth as a result of big (Earth) data, the Internet of Things, social media and new participatory approaches in which people contribute to sensing the environment were partially foreseen by Goodchild et al. (2012) and Craglia et al. (2012). What we did not expect was that the convergence of data and computing availability would lead to a major change in the development and use of artificial intelligence (largely since 2012) (Craglia et al. 2018) and that Earth observation would become such a big business for private sector companies and investors. Data seem to be the more significant change factor of the last decade, and therefore, this chapter focuses on reviewing the recently adopted approaches to assess the value of EO data, building on a study carried out at the Joint Research Centre by Pogorzelska (2018), as a lens through which to see the value of Digital Earth.

¹<https://www.investopedia.com/terms/e/economic-value.asp>.

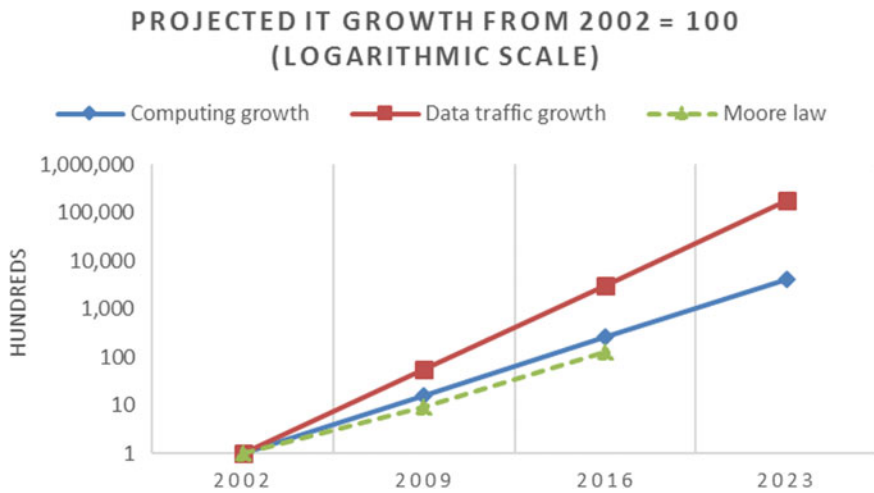


Fig. 19.1 Projection of data and computing growths (**logarithmic scale**). *Source* JRC based on Kambatla et al. (2014)

This chapter is organized as follows. After the Introduction, Sect. 19.2 outlines different viewpoints on the value of EO, Sect. 19.3 reviews approaches and methodologies to assess the value of EO, and Sect. 19.4 draws conclusions that are relevant to Digital Earth.

19.2 Different Viewpoints on the Value of Earth Observation

19.2.1 Definition of EO

In this chapter, we adopt the definition of Earth observation as developed by the Group on Earth Observations (GEO). EO is understood as “the gathering of information about planet Earth’s physical, chemical and biological systems”² through a range of technological means such as satellites, aircrafts and drones, in situ measurements or ground-based monitoring stations. Remote sensing (RS) is a technique used in EO to observe objects from a distance without being in direct contact with them.

Various studies deal with EO as part of broader “geospatial data” or “spatial data”. The adjectives “geospatial” and “spatial” are usually used interchangeably. The term “spatial data” is legally recognized in Europe as defined in the INSPIRE directive (European Commission 2007) and means “any data with a direct or indirect reference to a specific location or geographical area” (ibid, Art 3). Spatial data,

²GEO: https://www.earthobservations.org/g_faq.html. Accessed 7 Apr 2019.

apart from EO, encompasses data from other technology segments such as the global navigation satellite system (GNSS) and positioning, geographic information systems (GIS)/spatial analytics, and 3D scanning.³ Since all of the above are relevant for Digital Earth, we use the GEO definition and therefore use EO as a broad label that also covers (geo)spatial data.

19.2.2 Value for Whom?

The value of data and information varies according to who values it and for what purpose, and often also carries a time dimension, i.e., some data may very valuable now (e.g., stock market prices or agricultural yield data) but almost worthless in a few hours (Blakemore and Craglia 2006).

The socioeconomic value of EO data is often greater when combined with other data. The value for a user of a digital map is greater when one can also navigate to a chosen destination as a result of combining EO data with location data. The value can be greater still if EO is combined with the social data of other participants in traffic because predictions of the traffic flow can be made and alternative routes can be proposed (to measure the value of a digital map, see, for example, Alpha Beta 2017). The value of EO data is easier to appreciate from the perspective of an individual in the mass market because of the daily use of EO-based solutions; assessment of the value of EO from the perspectives of the public and private sectors is more complex.

19.2.2.1 Public Sector Perspective

Governments have traditionally been the main users of various forms of geographic information, such as maps, for taxation, way-finding, navigation, and defense. With the expansion of commercial aviation and the launch of civilian space programs in the twentieth century, the public sector, often in partnership with the private sector or through private sector contractors, continued to remain the main producer and user of EO, largely for scientific purposes, weather monitoring and forecasting, and to support policy in the environmental, societal and economic domains. The public sector greatly relies on EO data—often combined with social and economic data—to help inform policies directed towards a range of environmental and socioeconomic objectives. The environmental policy objectives that rely on EO information revolve around the management of natural resources and battling environmental threats such as land, air and water pollution, deforestation, biodiversity loss, and climate change.⁴ The EO-supported social policies touch on citizens' wellbeing and include areas such as security and defense, science, education, agriculture, safety and rescue, disaster

³Geospatial Media and Communications (2018), p 14.

⁴Science for Environment Policy: Earth Observation's Potential for the EU Environment, Copernicus: http://www.copernicus.eu/sites/default/files/library/FutureBrief6_Feb2013.pdf.

and disease response, health, transport and urban planning. Economic objectives include the development of innovations, knowledge and solutions that can increase competitiveness and create new products, services, and prosperity. In Europe, there has been a noticeable shift in EO policy to add objectives aimed at developing the digital single market and harnessing opportunities for economic growth and jobs in the private sector.

From the standpoint of the public sector, the value of EO mostly lies in informing policy making and decision making. EO can inform the full policy cycle: it helps identify needs and areas for policy intervention, formulate policies, and tailor regulatory responses that can use legal tools that rely on EO to support policy implementation and decision making. EO also supports policy monitoring and policy change.

There are numerous examples of how EO supports policy making. To identify policy intervention areas, satellite imagery allows for realizing the scale and rate of deforestation, for example, in the Amazon rainforest, which eventually led to passage of a regulation that resulted in a significant decrease in the pace of deforestation (see, for example, Finer et al. 2018).

As far as lawmaking is considered, the most visible use of EO is as a regulatory compliance tool (Purdy 2010), especially in enforcement of environmental legislation. There are at least three forms of the use of EO as a regulatory compliance tool: (a) as part of a targeted enforcement strategy to monitor specific laws, (b) in monitoring of individual sites or areas where environmental offenses have occurred, such as marine pollution (Wahl et al. 1996), and (c) as a form of historical evidence. There is a form of targeted regulatory monitoring, for example, in the agriculture sector in the EU, where legislation gives Member States the option of using data from “unmanned aircraft systems, geo-tagged photographs, GNSS-receivers combined with EGNOS and Galileo, data captured by the Copernicus Sentinels satellites and others” to monitor farm subsidy payments under agricultural cross-compliance schemes (European Commission 2018). The introduction of EO to replace or supplement on-field checks is aimed at reducing both the administrative burden on the EU member states and the cost of monitoring farm subsidies for potential fraud. For example, Australia incorporated satellite surveillance of tree clearing in the policy strategies of relevant legislation (Purdy 2010). EO data have also been increasingly used as evidence. Systematic archiving of satellite images provides regulators or a court with a relatively impartial snapshot of any location at any given time, providing accurate evidence that would often be otherwise unavailable. Such satellite imagery has been used as evidence in lawsuits. In the 2012 UK pollution case, satellite images were used as primary evidence to prove the breach of UK maritime pollution legislation by Maersk Tankers Singapore; in another case in the US, imagery was used to show false insurance claims (Rocchio 2006).

Regarding policy implementation, public institutions use EO for their decision making. Large financial institutions such as the World Bank or the Asian Development Bank often tailor their official development assistance (ODA) in accordance with EO-based environmental information.⁵ Another example of the use of EO data

⁵ESA: http://eo4sd.esa.int/files/2017/10/1_esa_eo4sd_and_sdgs_oct_2017.pdf.

is the US federal decision making for drought disaster assistance, which heavily depends on drought indicators fed by EO data (Steinemann et al. 2015). Finally, EO supports the statistics necessary to monitor progress towards policy objectives (see UN 2017) and helps evaluate the outcomes and necessary changes to policies (see BRYCE 2017).

The last decade saw a huge increase in the number of EO satellites, including privately funded ones; combined with advancements in ICT, EO satellites changed the way that public institutions can use EO data and information. Due to the satellite-based infrastructure, EO data now provide insights into nearly real time geographical distributions of various phenomena that are commensurable across countries, regions and cities, allowing for timely and targeted responses to various needs or threats. Open and free access to data and analytical tools, advances in algorithms and data processing have started to enable the widespread use of this information. Harmonized and interoperable EO data infrastructures are often combined with other geo-referenced sociodemographic, economic and public administration data to make the indicators and analysis more robust and international reports more harmonized (OECD 2017). This eventually equips public institutions with tools that allow for better cooperation, particularly in face of challenges of a global scale. In this respect, the global cooperation achieved through the Group on Earth Observations (GEO)⁶ is also important.

19.2.2.2 Private Sector Perspective

Whereas the EO upstream and end-user segments used to be significantly dominated by the governmental institutions, the private sector has been traditionally more pronounced in the EO downstream segment concerned with the creation of added-value products and services. Because the existing EO market was mostly driven by the demand from the public sector, particularly from the defense and security segments (ca. 60%, see Keith 2016), in 2014 there was still no functioning EO market (Smart 2014). The last few years witnessed the staggering growth of the EO market (European Commission 2017) in both the amount of money flowing to the EO sector economy and the number of new players at all levels of the EO value chain. These are good indicators of the advancement of the EO market towards maturity.

To large extent, the fast maturing of the EO market has been enabled and driven by technology developments in both the upstream and downstream EO segments. The miniaturization of satellites and the reusability of rockets were upstream-related technology developments, and increased analytical capabilities coupled with the enhanced ICT infrastructure reshaped the EO sector from the bottom. The former developments allowed for democratization of the access to space and vertical integration across different sectors; and the latter created a significant thirst for data outside the public sector and demand from the individual mass markets (e.g., digital imagery). These developments heavily impacted the dynamic in the whole EO sector.

⁶<http://earthobservations.org>.

They facilitated different forms of collaboration between the public and private sectors. Currently, innovative companies and businesses more actively contribute to the socioeconomic policymaking by proposing solutions based on the innovative technological developments (for the issue of building partnership between the sectors, see EARSC 2014).

Technology developments also enabled different business models and contributed to the growth of the individual mass market. The space industry has developed into a multibillion-dollar industry with global revenues increasing from \$175 billion in 2005 to almost \$385 billion in 2017—a growth rate of approximately 7% per year (US Chamber of Commerce 2019). According to Morgan Stanley (2018), the global space industry could generate a revenue of \$1.1 trillion or more in 2040, with almost 50% of projected growth coming from satellite broadband internet access. While the demand for data has been growing at an exponential rate, particularly with the increasing demand for bandwidth from autonomous cars, the Internet of Things, artificial intelligence, virtual reality, and video, the cost of access to space (and, by extension, data) is falling rapidly. With the development of reusable rockets, the cost to launch a satellite has decreased from approximately \$200 million to approximately \$60 million, with a potential drop to as low as \$5 million, according to Morgan Stanley (2018). The mass production of pico satellites such as CubeSat has brought costs down from hundreds of millions to several thousand dollars,⁷ so that companies such as Planet can afford to send dozens of satellites in space every launch and operate a constellation of over 150 satellites orbiting the Earth. This is creating entirely new markets as an increasing number of companies offer daily high-resolution images of the Earth to monitor change. It also creates opportunities for companies providing launch and ground-segment facilities. In November 2018, Amazon Web Services announced the deployment of their first ground stations, with an aim of having 12 operational by mid-2019 and expanding their business to pay-as-you-go EO (Barr 2018). This announcement is potentially a big step in the expanding market for EO given the market size and reach of AWS.

The amount of private sector capital in the space sector is staggering, considering that this industry was dominated by large government-backed national space agencies until recently. According to Seraphim Capital, a venture capital fund, the amount of VC in the space sector was \$3.25 billion in 2018, up 30% from 2017, with over 180 companies receiving backing, an increase of over 40% compared with the previous year. The launching sector received the highest investment flow of just over \$1 billion in 2018 and data collection platforms (satellite constellations and drones) followed closely behind at \$868 million.⁸ Notably, China is also becoming a big player in the commercial space market since the government opened the country to private investment in 2014. In 2018, China became the world's top launch provider, with 39

⁷<https://space.stackexchange.com>.

⁸<http://seraphimcapital.passle.net/post/102f50i/seraphim-q3-global-space-index-investment-remains-concentrated-in-launch-and-co>.

launches versus 34 from the US, and its BeiDou GPS navigation constellation aims to rival the American (GPS) and European (Galileo) satellite navigation systems.⁹

While the development of the space industry is making the headlines, there are many other areas in which private sector companies are investing in geospatial data capture, processing, and value-adding, which are relevant to the further development of Digital Earth. Examples include well-established companies such as Trimble, which traditionally serviced the surveying and construction industry, and has now expanded into mining and precision agriculture; DigitalGlobe, which has moved from being a data supplier to a solution provider for specific sectors such as the automotive industry¹⁰; and new companies such as NextNav, which specializes in indoor positioning systems with a dedicated infrastructure of indoor antennae for applications including geo-advertising, public safety, and emergency services.

The increasing availability of EO with integrated multiple sensors from both space and the ground together with processing power and storage at diminishing costs, business models based on pay-as-you-go for everything-as-a-service and the development of AI algorithms to process the data and extract meaningful information are opening EO to a much wider audience of companies that are not experts in EO or geo-processing. A good example is Orbital Insight, a start-up established in 2013 that combines detailed imagery provided by companies such as Planet with public sector data and develops AI algorithms to provide solutions for specific sectors such as energy and advanced consumer intelligence.¹¹

The above mentioned technology developments can also be linked to the creation of the distinguished ramification of the EO market, namely, the EO data market, which does not quite fit the traditional upstream or downstream EO segments but rather conveniently nests in between, being pulled by the gravity of the big data market. The commercial EO data market was estimated at EUR 1.5 billion in 2015 with the opportunity to grow to EUR 2.6 billion in 2025 (European Commission 2017). While upstream companies naturally expanded into this market segment and benefit from selling VHR EO or data products, the new influx from outside the EO sector is a relatively new phenomenon. The big IT techs such as Google or Facebook introduced new business models to the EO domain. They do not seek profits from selling EO data or EO-based services or products but profit from business intelligence based on combining EO big data with different streams of other data, especially location and social data. In such cases, IT platforms play the role of a content aggregator that can satisfy different customer needs while making profits from targeted advertising based on big data-based business intelligence. The recent developments by Amazon and Google are in this direction.

While the market is changing so rapidly, assessing the value of EO from both economic and social perspectives is not easy. In the next section, we review some

⁹<http://seraphimcapital.passle.net/post/102fd5w/seraphim-space-predictions-2019>.

¹⁰<https://www.digitalglobe.com/markets/automotive>.

¹¹See Orbital Insight: <https://orbitalinsight.com/products/go-energy/> or <https://orbitalinsight.com/products/go-consumer/>.

recent studies that estimated such value and then assess the extent to which they can inform the analysis of the economic value of Digital Earth.

19.3 Review of Approaches and Methodologies to Assess the Value of EO

Assessing the value of EO has been the subject of research for several years worldwide (Borzacchiello and Craglia 2011). The interdisciplinary and cross-cutting nature of the use of EO data resulted in a wide range of approaches to identify and measure the value of EO. A review of recent studies on the subject by Pogorzelska (2018) identified three main clusters of approaches. The first focuses on capturing economic value of EO and gathers micro- and macroeconomic methodologies. The second enters the discussion on EO value through the more interdisciplinary conceptual framework of the value of information (VOI). Since EO exhibits characteristics of an all-purpose infrastructure good, many have noted that measuring the value of EO in a comprehensive and exhaustive way is impossible; therefore, some approaches primarily focus on ways to maximize its value. The third cluster gathers methodologies concerned with maximization of the value of EO through enhancement of the data infrastructure and open access to EO data. These clusters are by no means exhaustive or exclusive. They represent different perspectives or entry points to the discussion and are often combined within one study. The methodologies used within one cluster may be used along with others or adapted to serve a specific purpose (e.g., VOI studies adapt micro- and macroeconomic methodologies to reflect value of EO-based information).

19.3.1 Value of Information (VOI) Approach

The studies framed by the value of information generally examine how EO-based information can be tied to decision making, how those decisions can be linked to societal outcomes, and how those societal outcomes produce value.

VOI studies underline that the value of information is tightly linked to its use. Barr and Masser (1997) claim that “information has no inherent value, it is only of value once used and that value is related to the nature of the use rather than the nature of the information [thus] information has very different values for different users.” EO-derived information is valuable when it informs decisions aimed at achieving various environmental, social and economic benefits.

Since the value of EO-derived information changes depending on the specific use and the user, VOI studies also deal with different value propositions. Macauley (2005) proposed a framework to provide a common basis to evaluate information depending on the type of user. Macauley (2006) also provided a theoretical foundation

for establishing the value of space-derived information and a framework that uses economic principles.

As far as the subsequent quantification of this value is considered, the VOI approach gathers a very diverse set of methodologies. There have been ongoing efforts in the fields of GIS and related systems as well as remote sensing to accelerate the development of methodologies to quantify the benefits arising from EO-based decisions. Meta reviews of the literature in this field have been carried out, for example, by Lance et al. (2006), Genovese et al. (2009), Richter et al. (2010). GEO-related work and research focused on remote sensing have been carried out, for example, by Fritz et al. (2008) and Ryzak et al. (2010).

While there is a widely recognized need for EO value to denote a quantitative measure, many agree that it does not need to be expressed in monetary terms (Borzacchiello and Craglia 2011). The VOI economists usually seek to monetize the difference between decisions made with and without the EO-derived information (Gallo et al. 2018). However, the benefits are often expressed in nonmonetary terms such as in reductions in mortality and morbidity, reduced damage to capital assets, improved community well-being, time saved, fuel saved, reduced carbon emissions and many other social and economic measurements (Kruse et al. 2018). Studies have identified a set of methodologies used to quantify the value of EO-derived information, e.g., McCallum et al. (2010), Borzacchiello and Craglia (2011), Slotin (2018). The range of the methodologies identified includes the following:

- Value-measuring methodology (VMM) was developed to calculate the return on investment (ROI) relating to decisions based on intangible values.¹² It was adapted by the International Institute for Applied System Analysis (IASA) to assess the benefits of the EuroGEOSS;
- Impact-based methodology—this methodology determines value by qualitatively assessing the causal effect of information availability on economic and social outcomes, or the costs in terms of inefficiencies or poor policy decisions due to limited or poor-quality information;
- Systems dynamics modeling—like the methodology above, it measures the impact of EO-derived information. The value of EO is described through system dynamics models, where a change in one variable (e.g., EO-based information affects other variables over time, for example, the FeliX model¹³);
- Bayesian belief network—this conventional statistical approach assumes that people's expectations are updated when new information is available (for use of the methodology, see, for example, Bouma et al. 2009);
- Regulatory cost-effectiveness—this methodology assesses the direct cost savings achieved when a regulatory framework is in place;
- Willingness-to-pay methodology—this methodology concentrates on monetization of benefits through surveys of individuals and private and public institutions

¹²The VMM was initially developed by the Federal Chief Information Officers Council (2002) and applied in a case study by Hamilton (2005).

¹³www.felixmodel.com.

that estimate their willingness to pay or the amount they are willing to accept for not having the data/information; and

- Case-based monetization of benefits—this method focuses on measuring (often monetizing) the benefits resulting from a specific EO-supported decision, solution, product or service. The approach usually relies on qualitative analysis to identify and measure the benefits that arise.

19.3.2 Economic Approaches

This cluster of approaches gathers macro- and microeconomic methodologies to capture the economic value arising in the context of EO. This set of methodologies has clearly become more relevant as the EO market has matured.

Macroeconomic

This group of approaches enters the discussion on the value of EO from the perspective of the economic impact of the EO sector on the economy and links the value of EO to the macroeconomic statistics characterizing the sector. The macroeconomic methodologies include the following:

- GDP impact assessment—this approach focuses on calculating the return on public investment in the EO sector. The following indicators are usually taken into account: investment of the upstream sector, spending by suppliers, wages/salaries of employees, employment impact, government tax revenues (income direct tax, VAT, employer social security contributions, employee social security contributions; see, for example, Strategy 2015);
- Economic impact assessment—focuses on the use of specific economic tools to assess impact, such as input-output tables and computable general equilibrium models (CGEM); and
- EO value chain approaches—these approaches focus on assessment of the value of EO across a whole value chain. A specific value chain is identified and qualitatively analyzed. The methodology usually relies on quantification of the value of EO as the increase in revenues and reductions in costs related to the EO-supported activities, compared with a situation where no EO-derived solutions are available (see, for example, PwC 2016).

Microeconomic

Microeconomic approaches focus on EO market characteristics and market approaches to value EO data and customer behavior. This cluster includes the following:

- Characterization of the EO market—this approach focuses on EO expressed through the statistics characterizing the EO market, the EO data market and specific markets for EO-based solutions, products and services;

- Stated/revealed preferences—these methods assess the value of EO-derived data/information through the amount that users are willing to pay or the amount they are willing to accept for not having the data/information;
- Market equivalent pricing—this is the market price that should have been received if the statistical or EO data outputs were sold in a market environment. This approach approximates market prices by looking at the market prices of similar data products, such as those from companies that offer data for prices, or business trends drawn from a range of sources including open government data;
- Cost-based derivation—this method determines value based on the full cost of producing the data, statistics or information; and
- Discounted cash flows (DCF) methodology—this method ascribes a value/price to a specific dataset (intrinsic value) based on a projection of its future cash flows that is discounted to today's value.

19.3.3 Approaches Concerned with Maximization of EO Value

This group of approaches recognizes that, although measuring EO value is difficult and relative, if not impossible, the improvements in the EO data infrastructure and open access to data are key prerequisites for maximizing the value of EO. This cluster often uses impact-based methodology to demonstrate how data infrastructure investments and removal of specific barriers to access data affect or may affect people's lives or the economy. With respect to this approach, Slotin (2018) argues that “[b]y linking to real-life outcomes, impact-based case studies show how investments in data systems can translate into meaningful outcomes for people.” Many case studies show these impacts, including deliberate experiments such as randomized control trials and retrospective assessments of impact¹⁴ (Slotin 2018).

19.3.3.1 Spatial data infrastructure

Spatial data infrastructures (SDIs) have been (largely) public sector-led investments by governments across the world to increase the availability and accessibility of geospatial data for public policy, an informed society, and market development. The development of SDIs has been documented by many studies, including by Masser (1999, 2005), Williamson et al. (2003), Cromptoets et al. (2008). For many years, the global community of researchers and practitioners of SDIs gathered through the Global SDI association,¹⁵ which was formed in 2004 and dissolved in 2018. Now, global discussions on SDIs are held in many groups, including the International

¹⁴See, for example, www.dataimpacts.org.

¹⁵www.gsdiassociation.org.

Society for Digital Earth,¹⁶ the UN Committee on Global Geospatial Information Management¹⁷ and the Group on Earth Observations, to coordinate efforts to develop a global Earth observation system of systems (GEOSS).¹⁸

In Europe, the adoption of the INSPIRE directive in 2007 (European Commission 2007) provided a major impetus towards the assessment of spatial data infrastructures and their socioeconomic impacts. A study on the expected economic impact of INSPIRE was carried out in 2003–2004 prior to adoption of the law (Inspire and Craglia 2003; Dufourmont et al. 2004). Progress in over 30 European countries on the implementation of SDIs was reported in a set of studies by Vandembroucke and Janssen (2008). Crompvoets et al. (2008) collected a range of theoretical perspectives informing the work on SDIs and focused on the improvement of SDIs. Vandembroucke et al. (2009) proposed the application of a network perspective to SDIs. The increased availability and quality of data and data sources are believed to help inform the actions taken by decision makers and the resulting socioeconomic benefits (Kruse et al. 2018).

19.3.3.2 Open access to data

Maximization of the value of EO through open access to data is similar to the previous approach. It primarily differs in the entry point to the discussion. Instead of focusing on the infrastructure, this approach focuses on the benefits of open access to EO data as a part of bigger data ecosystem. It considers access to data a key factor in determining EO-enabled creation of added value and promotes the openness of data.

Approaches that address the value of EO from the perspective of open data often focus on “unlocking the value of open data” via removal of specific barriers to data, not on measuring the actual value of EO. A study by McKinsey (2013) found that open data can help unlock 3.2 trillion to 5.4 trillion USD in economic value per year across seven chosen domains: education, transportation, consumer products, electricity, oil and gas, healthcare, and consumer finance.

From the economic perspective, the term “open data” falls back on the economic notion of a “public good”. As a good, EO data are not homogenous. A public good is a type of good that, once produced for some consumers, can be consumed by additional consumers at no additional cost.¹⁹ The definition includes the two main characteristics of a public good, nonrivalry and nonexcludability. “Nonrivalry” means that the consumption or use of the good does not diminish or remove the availability of the good to others. “Nonexcludability” means that everyone has access to a good since no exclusion mechanisms are in place. In contrast to public goods, private goods are often rivalrous, i.e., the consumption or use of the good diminishes or removes

¹⁶<http://www.digitalearth-isde.org>.

¹⁷<http://ggim.un.org>.

¹⁸<https://www.earthobservations.org>.

¹⁹For public good theory, see Holcombe (1997). For the theory of public expenditure, see Samuelson (1954).

the availability of the good to others, and excludable, i.e., prices, licenses and other exclusion mechanisms effectively control the number of beneficiaries, and property rights are applied to establish legitimate ownership. If nonpaying users cannot be excluded from benefits, then the market for the good fails as a result of free-riding (Harris and Miller 2011; Pearce 1995).

In general, EO data are largely nonrivalrous although some technical measures may be put in place to limit the number of users and applications. Although non-rivalrous, EO data tend to vary on the scale of excludability, which resulted in the heterogeneous landscape of the economic nature of EO data (for a proposition of mapping economic goods on the two axes of rivalry and excludability, see Harris and Miller 2011). This variation in excludability is reflected in the international legal provisions relating to access to RS EO data. The Remote Sensing Principles,²⁰ while promoting widespread access to satellite remote sensing data, contain a provision on the possibility of “provision of data on reasonable cost terms”.²¹

The resulting regional and national regulatory frameworks allow for varying access to EO data. For example, the 2016 US Common Framework for Earth Observation Data states that “[a] core principle of the U.S. Government is that Federal Earth-observation data are public goods paid for by the American people and that free, full and open access to these data significantly enhances their value”.²² In the EU, the Copernicus Regulation provides that Copernicus data shall be made available on a full, open and free-of-charge basis. This general provision suggests that Copernicus data are a public good. Nevertheless, *lex specialis* provides for a series of possible access limitations that include (a) licensing conditions for third-party data and information; (b) formats, characteristics and dissemination means; (c) security interests and external relations of the Union or its Member States; (d) risk of disruption, for safety or technical reasons, of the system producing Copernicus data and Copernicus information; and (e) ensuring reliable access to Copernicus data and Copernicus information for European users.²³

Similarly, other EU key regulations on data such as the Public Sector Information (PSI) directive (European Commission 2013) or INSPIRE directive (European Commission 2007) do not guarantee free access to governmental data. They all promote the idea of open data and encourage public institutions to open the vaults of their data, resulting in large amounts of data, including EO information, that exhibits characteristics of a public good (Uhlir and Schroeder 2007; Smith and Doldirina 2016). The opening of the vaults of PSI is often considered a boost for democratic accountability and for business to create value-added products, foster innovation and

²⁰RS Principles, Principle XII.

²¹Since the term “reasonable cost” is not defined, Harris and Baumann (2015) suggest that compared with many other EO data policies, the term should be interpreted as the marginal cost or the cost of fulfilling a user request.

²²US National Science and Technology Council: Committee on Environment, Natural Resources, and Sustainability (2016) Common Framework for Earth Observation Data. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/common_framework_for_earth_observation_data.pdf.

²³Copernicus Regulation, Article 23(2).

Table 19.1 Summary of studies, approaches and methodologies

Study	Approach	Main methodology
PwC 2016	Economic approach/GDP impact assessment (upstream and downstream space sector)	Revenue and reduction in costs attributable to the use of Copernicus-based solutions across 8 specific industries (value chains)
Geospatial Media and Communication (2018)	Economic approach/combination of micro- and macroeconomic approaches	<ul style="list-style-type: none"> – Characteristics of the global geospatial/EO market (size and trends) based on surveys and secondary sources; – Value impact of the EO solutions on the global economy; – The country readiness index for the absorption of the geospatial/EO solutions
Alpha Beta (2017)	VOI	Quantification of indicators relevant for estimation of the environmental, social and economic benefits arising from the use of digital maps for individual users and the private sector
OECD (2016a)	VOI	Quantification of indicators relevant for capturing knowledge and innovation spillover effects relating to EO
Miller et al. (2013)	VOI	The willingness-to-pay methodology—monetization of the benefits for the users of Landsat imagery. Survey-based
OECD (2016b)	Maximization of EO value/data access	Qualitative and conceptual analysis of the possible forms of data access
OECD (2014)	Economic approach	Indicator-based statistics on the digital economy (focusing on closing gaps in the measurement of the digital economy)
Cattaneo et al. (2016)—EDM Report	Economic approach: value of EO/the EU data market	Characterizes the European Data Market (EDM) through identification and measurement of a set of indicators within the private sector
EARSC and The Green Land case studies (2016a, b, and c)	VOI	Case-based monetization of benefits. Monetization of indicators relevant for estimation of the benefits/impacts arising from the use of a specific EO-based solution

create jobs (Fornefeld et al. 2009; Uhler 2009). In addition, by alluding to the notion of public good and accountability, advocates of open data emphasize the need and legitimacy of science in the policy sphere (Arzberger et al. 2004).

Since increasingly large amounts of EO data exhibit characteristics of a public good (Smith and Doldirina 2016), the EO market has primarily developed around the value added to EO data in form of processed EO data or/and information as well as EO-derived services and products that also integrate other data (for adding value with the use of open data, see, for example Berends et al. 2017). To add value to EO data, the high uptake of EO data is critically important. Delponte et al. (2016) identified a set of barriers to space market uptake originating in the areas of policy, governance, technology, skills, and the market itself. To overcome these barriers, various public initiatives have been put in place. For example, the European Commission, in cooperation with the ESA, is providing financial support to develop the Copernicus Data and Information Access Services (DIAS).²⁴ The DIAS are expected to be an access point to Copernicus data and to provide processing resources, tools and other relevant data to boost user uptake and stimulate innovation and the creation of new business models based on EO data.

The Table 19.1 summarizes the studies reviewed and the approaches summarized above.

19.4 Conclusions

In this chapter, we approached the economic value of Digital Earth with a broad definition of economic value, i.e., the measure of benefits from goods or services to an economic agent and the trade-offs the agent makes in view of scarce resources. This definition implies that the benefits that can accrue to the economic agent (person, firm, or organization) can be more than economic in nature and can encompass environmental or social benefits.

The complexity of determining the value of Digital Earth is multilayered. A first level of complexity stems from the multiple definitions of Digital Earth introduced in Chap. 1: as a concept, an information system, a data organization principle, a multidisciplinary endeavor, and a science. With such multiple and heterogeneous perspectives, there is no single value of Digital Earth to measure and there is a whole range of values depending on the point of view. A second level of complexity is exposed when deconstructing Digital Earth into its key components: data, models, technology, and infrastructure. In this chapter, we focused on EO data because it is undergoing the most dramatic change at the beginning of this century. However, the value of EO critically depends on the value for whom, for what purpose, and when.

As indicated in Sect. 19.2.2.2, the commercial EO data market is reaching a level of maturity fueled by the availability of big EO data, cloud-based processing facilities, increased connectivity, and new business models based on everything-as-a-service.

²⁴<http://copernicus.eu/news/upcoming-copernicus-data-and-information-access-services-dias>.

This maturity is indicated by the level of private investments in the EO market for all segments, including the launching of satellites, data processing, integration, and value adding. However, there are no published studies with repeatable methodologies on the economic return of these large investments.

With this in mind, we reviewed the available recent studies to assess the value of EO/geospatial/open data and related infrastructures and illustrated that the variety of purpose and applications requires multiple approaches. We identified three main sets of approaches that focus on the value of information, the economic approach to the value of EO to the economy from both macro- and microeconomic perspectives, and a third set aiming at maximizing value through infrastructure and policy. Each of these sets of approaches has something to offer to the understanding and valuation of Digital Earth. The conclusion that there is no single answer to the question posed at the beginning of the chapter is not a bad thing: it acknowledges that Digital Earth is a global concept in which everyone can recognize their viewpoint and collaborate with others to increase the common good. Ultimately, the true value of Digital Earth may rest in its values as a metaphor to increase global understanding and communication across disciplines and between science, policy, and civil society.

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