Resources Policy 43 (2015) 91–100

Contents lists available at ScienceDirect

Resources Policy

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

The economic value of geological information: Synthesis and directions for future research

Elisabeth Häggquist*, Patrik Söderholm

Economics Unit, Luleå University of Technology, SE-97187 Luleå, Sweden

ARTICLE INFO

Article history:
Received 5 May 2014
Received in revised form
29 September 2014
Accepted 6 November 2014
Available online 23 December 2014

Keywords:
Geological information
Earth observations
Economic value
Benefit assessment

ABSTRACT

Geological information can play a key role in addressing challenges of sustainable development such as land degradation and groundwater protection, and contribute to improved decision-making processes. In this paper we: (a) provide a review of previous research on the economic value of geological information and other earth observations as well as related products, services and infrastructure; and (b) identify important lessons from this work as well as methodological challenges that require increased attention in future research. The review of prior research shows significant economic benefits attached to the generation of this type of public information. The value of geological information has typically been measured in terms of avoided costs. Still, it is difficult to compare results across studies since they differ in scope and make alternative assumptions concerning which sectors to cover. Furthermore, previous research is not uniform in their treatment of potential (rather than only existing) users, and employ varying conceptions of avoided costs. The paper concludes that future research should devote more attention to the public and experience good characteristics of this type of information, thus highlighting the preconditions for information adoption as well as addressing the role of potential users. A number of specific methodological challenges also deserve further scrutiny in future research, such as the use of discount rates and benefit-transfer approaches. We also provide some thoughts on how to proceed with such research.

Introduction

Background and motivation

Earth observations (e.g., of a geological, meteorological or topological nature) may have profound impacts on our everyday lives, but most people are generally not well informed about the economic values attached to this type of information. In this review paper we address the ways in which such values can be comprehended and measured, report results from previous studies, and identify important issues and challenges for future research.

Natural processes and human activities often cause stress to the environmental system's capacity. Having reliable information about such impacts is therefore a critical input into a large number of decision-making processes involving potentially significant environmental impacts (Bernknopf et al., 1993; Swedish Geological Survey, 2012). When natural phenomena, such as landslides or earthquakes, are better understood important societal costs can be avoided (Berg, 2005). For this reason, geological information and other types of earth observations are important for addressing the challenges of sustainable development (Grant and Williamson, 1999; Ting, 2002; Rodriguez-Pabon, 2005).

In brief, geological information could be – and is often – useful for decision-making in a wide range of societal activities, such as: (a) the development, sustainable use and protection of groundwater; (b) environmental impact assessments; (c) the exploration and development of minerals and fuels; (d) understanding and managing the causes of geologic hazards; (e) the construction of infrastructure projects; (f) city planning including zoning and landscaping; and (g) regional planning such as siting and permitting industrial facilities (Bhagwat and Ipe, 2000; Swedish Geological Survey, 2011).

A noteworthy example of a product containing geological information is the geological map. It describes the physical world by linking spatially based information, geological materials and geologic structures. Geological maps also add time and space interpretations on how these materials and structures interact. Improved geological information in terms of novelty and resolution, e.g., communicated through a geological map, may generate several benefits. It could influence mineral exploration and investment by reducing the risks at the early stages of the exploration process (Bernknopf et al., 2007; Scott et al., 2002). Moreover,

* Corresponding author. Tel.: +46 72 560 11 57.
E-mail address: elisabeth.haggquist@ltu.se (E. Häggquist).

http://dx.doi.org/10.1016/j.resourpol.2014.11.001
0301-4207/

excavations are dependent on accurate knowledge concerning soil conditions.

The costs of providing geological information are connected to the collection of the information and subsequently to the compilation, database construction, publication and distribution. The bulk of the costs are borne up front, in part since the gathering of new geological information such as maps is labor intensive, and requires field work and a highly skilled staff. The distribution costs are instead relatively low, and the costs of serving an additional customer are therefore also low. Moreover, the costs of providing geological information can be accessed via existing market prices, such as wages for skilled workers (Cressman and Noger, 1981) and the market prices of other inputs (Castelein et al., 2010).

However, whereas the costs of providing geological information are fairly straightforward to assess, this is typically not true for the economic benefits of such provision. First, the costs occur in the present while the benefits are allocated over time, thus motivating the use of appropriate social discount rates. Second, several users can appropriate the benefits of the information at the same time (i.e., non-rivalry in consumption), and the information is in part non-exclusive in use. Due to these public good characteristics geological information is typically not effectively priced in existing economic markets.

Since public goods typically are underprovided in the free market, this sets the stage for the government's interest in the provision of geological information. Geological information is mainly collected and analyzed by national government-funded geological survey agencies. Bhagwat and Ipe (2000) suggest that in the absence of government funding very little geological information would be provided.

In addition to this, critique has been expressed concerning the amount of government funding towards the generation of geological information and the existing distribution trends of such information. Reedman et al. (2002) argue that the provision of geological information often is inadequately funded and as a result poorly informed decisions may lead to substantial economic losses for society. A related critique has been directed towards the use of earth observations in general. For instance, Booz Allen Hamilton (2013) estimates that earth observation data saved USD 24–72 million in avoided revenue losses and avoided aircraft damages after the Eyjafjallajökull volcano eruption in 2010. Still, the authors conclude that if the ash cloud data had been implemented and used directly from the time of the eruption (and not with a one-week lag), the total avoided costs could have been as high as USD 200 million.[1]

A comprehensive assessment of the value of geological information and other earth observations is not only important for judging the viability of investments in information collection and provision (Borzacchiello and Craglia, 2011), but also for identifying the sectors of society that would benefit the most from such efforts (Castelein et al., 2010). Craglia and Nowak (2006) remark that since many countries have established new spatial data infrastructures[2] increased attention needs to be devoted to assessing the social and economic impacts of such infrastructure. In addition, Craglia et al. (2012) note that there has not yet been any convergence of the reference methodology, and there is therefore a need for more consistent methodologies aiming at valuing earth observations.

The potential societal and environmental importance of geological information motivates a closer scrutiny of how the associated economic values have been defined and assessed in previous work. Such a review of existing research in terms of theoretical foundations, and methodological and empirical scope is important for identifying gaps in the academic literature as well as unresolved challenges that ought to be addressed in future research.

Objectives, scope and approach

The objectives of this paper are to: (a) provide a review of previous empirical research on the economic value of geological information (including any related products, services and infrastructure); and (b) identify important lessons from this work as well as issues and challenges that deserve increased attention in future research.

The paper focuses on previous research that has assessed the economic values of either geological information or other earth observations. The literature on earth observations is broad and fragmented into different fields, including geological, meteorological and topological research. The inclusion in this paper of studies assessing also non-geological information based on other types of earth observations is motivated by the similarities in the qualities – and economic characteristics – of such information. The methodological challenges involved in the valuation of information are also very similar across these research fields.

Previous work ranges from analyzing the value to many users of a marginal increase in the overall quality of the information to assessing the economic value of information in the context of specific decision-making situations (e.g., monitoring water quality with the help of satellite information or for mineral exploration decisions). Moreover, a number of studies explicitly address the value of spatial data infrastructure, including technological standards or policies that enable the use of, for instance, geological information in society. This latter work therefore provides a more complex picture of any associated information products and services.

In our search for previous research on the value of geological information, we employed a combination of different keywords. Specifically, we carried out searches on combinations of terms such as “societal value” or “economic value” on the one hand, and “geological information”, “earth observations”, “geodata” or “spatial data infrastructure” on the other in key bibliographic databases such as Web of Science, Science Direct, Wiley Online Library and Google Scholar. In order to find recently published literature, we forward-followed quotations on the articles identified by this keyword search. In addition, since the economics literature on assessing the economic value of geological information is relatively narrow a keyword search was also conducted on a wide range of national geological surveys in order to identify additional relevant work on the topic. In total about 25 reports and 11 peer-reviewed articles involving the economic assessment of geological information and/or closely related earth observations have been reviewed. Most of the reports are – even if not all are peer-reviewed in line with academic standards – well described (and cited) in the scientific literature.

Outline of paper

The paper proceeds as follows. In the next section we discuss geological information as an economic good, as well as the theoretical foundations for valuing such information. Most

[1] The London Volcanic Ash Advisory Center (VAAC) had not previously used the so-called Aura data. Hence, after the volcano eruption the VAAC had to work against the clock to develop, and deliver the requested data products. The data products were intended for the VAAC warnings and for European officials to assess which airspace to open. The VAAC first presented and used the Aura products on April 19, 2010, that is a week after the eruption began. By that time some flights had already resumed.

[2] Such infrastructure includes technology and information standards that are necessary in order to acquire, process, distribute, use, maintain, and preserve data. Geospatial standards are technical documents containing detail interfaces or encodings.

empirical work broadly defines this value in terms of the expected cost savings from having access to such information compared to not having access to it. Results and lessons from previous empirical research synthesizes the existing empirical work based on a categorization of the research by methodological approach and empirical scope, respectively. In Discussion and directions for future research we identify and discuss a number of important challenges and issues to be addressed in future research.

The value of geological information: theoretical remarks

The interest in the economic value of earth observation information has increased over the last decade, and at a number of recent workshops the value-generating processes have been discussed.[3] In brief, the economic value will be determined by in which way the information is processed and used. In general the benefits of earth-based information are considered largest when; (a) the information makes decision-makers indifferent towards alternative choices; (b) action can be taken in response to the information; (c) the consequences of making the wrong choices is large; (d) the constraints on using the information are few; and (e) the costs of using the information are low (Macauley and Laxminarayan, 2010; Borzacchiello and Craglia, 2011). Furthermore, the value should also be considered influenced by the characteristics of information as an economic good. In this section some theoretical foundations of valuation as well as important economic characteristics of geological information will be discussed.

The public and experience good characteristics of geological information

Geological information, such as geological maps, is a non-rival good as it can be reused and accessed by several users at the same time, without any congestion costs (Stephan, 2005). For the above reasons such information possesses clear public good features even though it must be considered a quasi-public good since the benefits accruing to society may be restricted through licensing, or due to intellectual property rights as well as a lack of competence among users (e.g., Stiglitz, 1999; Frank, 2001).

Nevertheless, scholars tend to agree that there are extensive positive economic externalities associated with the production of geological maps (e.g., Bernknopf et al., 1997; Bhagwat and Ipe, 2000; Berg, 2005).[4] The public good nature of geological information influences the assessment of the societal benefits since the decision-making process is not limited to the financial profitability of a given project alone (Bhagwat and Berg, 1991).

Geological information is also a knowledge-creating good (e.g., Bhagwat and Berg, 1991; Reedman et al., 2002), and according to Bhagwat and Ipe (2000) this is in contrast to many other public goods and services as the information remains intangible until it is applied for visible benefits. Still, the processes of generating knowledge typically suffer from imperfect information and matching problems. Acquiring information about the data gives rise to costs for the potential user (Krek, 2002).

In this paper we argue that since the economic benefits of geological information only emerge along with its use, these benefits possess some important characteristics associated with so-called experience goods (Krek and Frank, 2000; Nelson, 1970). All goods and services have some characteristics of an experience good, nonetheless such characteristics have been overlooked in the prior literature on geological information. In this paper we therefore highlight the effects of experience good characteristics such as: (a) learning-by-using and (b) location and context dependence (Andersson and Andersson, 2013).

A straightforward approach to elicit the economic value of geological information is to ask directly for the user's maximum willingness-to-pay (*WTP*) for the specific information. However, the public and experience good characteristics render great difficulties in presenting valid *WTP* estimates. Although the economics literature on public goods valuation through the use of survey techniques has developed a number of methods to avoid generating biased value estimates (e.g., due to strategic concerns of the respondent, hypothetical bias etc.),[5] the results from such investigations may still suffer from biases and be difficult to interpret. Furthermore, the experience good nature of geological information may exacerbate the problems of eliciting *WTP*, both for existing users of such information (due to the location- and context-dependent benefits) and for potential new users (due to the importance of learning-by-using). These methodological challenges suggest that more practical approaches may have to be considered, and we therefore present a theoretical framework that has been used frequently in previous research.

Theoretical framework

At a general level geological information creates value by improving different types of decision-making processes. The assessment of these values requires an understanding of how more or improved information could lead to superior decision-making while at the same time incorporating the individual objectives of the decision-maker. The decision-makers may in turn range from private companies such as mineral exploration firms (Bernknopf et al., 2007) to regulatory authorities considering, for instance, different land uses (Bernknopf et al., 1997).

In both cases the benefit assessment may be analyzed by comparing the economic impacts of decisions that would be made using the new information relative to decisions based on the already existing information. In monetary terms the value of information can therefore be expressed by identifying the losses averted from having access to the information and/or as a reduction in uncertainty. In the case of geological information the potential value may come from: (a) direct savings in terms of avoided costs from contaminations or erosion; (b) reduced potential for liability; (c) lower costs for groundwater protection; (d) safer infrastructure; and (e) improved mineral exploration efficiency (Bhagwat and Berg, 1992; Magesan and Turner, 2010; Kleinhenz and associates, 2011).

From a theoretical view the benefits of geological information can therefore be evaluated through a comparison between different cost minimization problems. In the following we outline the theoretical framework provided by Bhagwat and Ipe (2000), which has been frequently used in empirical work. In their setting a risk-neutral economic agent is preparing a project report for setting up a landfill, and this report makes use of geological information to improve decision-making.

[3] See presentations and reports from, for instance, the Group on Earth Observation 10th Summit "Understanding Socio-economic Benefits and Impacts" (2014), the INSPIRE Conference (2013) "Information for Innovation and Socio-economic Development" (2013), and the GEO Task workshop "Socio-economic Benefits From the Use of Earth Observation Workshop" (2011).

[4] It has been suggested that the knowledge generated by geological information does not diminish but is rather augmented by use (Stephan, 2005). For instance, once the mapping is carried out the information provided by the maps has the possibility to benefit everyone in similarity to the case of clean air (Bhagwat and Berg, 1991).

[5] These methods include cheap talk, discrete choice design, and certainty scales. See, for instance, Morrison and Brown (2009) or Champ and Bishop (2006).

The expected cost of preparing a project report of a given quality is denoted *EC*, and can be assumed to be a function of the efforts put into preparing the report, *T*, the geological information available, α, and the credibility of the report, *R*. *EC* increases with increases in both *T* and *R* (the latter due to, for instance, higher safety requirements), but decreases with higher α. Thus, we have

$$EC(T, \alpha, R) \text{ where } \frac{\partial EC}{\partial T} > 0, \quad \frac{\partial EC}{\partial \alpha} < 0, \quad \frac{\partial EC}{\partial R} > 0 \tag{1}$$

In Bhagwat's and Ipe's framework the economic agents' objective is to choose the level of effort *T* so as to minimize *EC* while at the same adhering to a certain minimum level of credibility, i.e., $R \geq \overline{R}$. Thus, $\overline{R}$ represents this minimum level of *R*.

By employing this simple theoretical framework we can compare the expected costs under two different situations, one with baseline information and one in which new or improved geological information is available. In the first of these situations there is only limited prior information about the geological conditions, here indicated by the subscript *p*. Here the agent will have to put in some extra effort to collect information in order to meet the credibility constraint. Still, in this setting the cost-minimizing agent has no incentive to overcomply with this constraint, i.e., the credibility of the report will equal $\overline{R}$. If the chosen level of effort is denoted T_p^*, the expected cost under cost-minimizing effort will thus be equal to

$$EC\left(T_p^*, \alpha_p, \overline{R}\right) \tag{2}$$

In the alternative situation new or improved geological information is available, and this increases the credibility of the project report. We use the subscript *m* to denote this available information case. Here the agent does not need to collect the geological information required to complete the project, and he/she can use all the information available and prepare a report that has a higher credbility than $\overline{R}$. The chosen level of effort in this case can be denoted T_m^*, and it follows that $T_m^* < T_p^*$. We thus have

$$EC\left(T_m^*, \alpha_m, R\right) \tag{3}$$

Eqs. (2) and (3) suggest that the value of the information, i.e., the expected cost savings (*ES*), will be equal to

$$ES = EC\left(T_p^*, \alpha_p, \overline{R}\right) - EC\left(T_m^*, \alpha_m, R\right) \tag{4}$$

Bhagwat and Ipe (2000) employ this framework to operationalize the minium and maximium value of geological information. The minimum value attained equals the amount of money that the cost-minimizing agent would have spent to collect the relevant information (had this not been available) but while maintaining the required credbility level. This is a minimum value since there is no use for the agent to invest in $R > \overline{R}$. Moreover, the agents could also be asked to state the amount of money saved because of the availability of the new or improved information. This would be a maximum value since in this case all the information available could be used to prepare a better project report.

Although the above approach has been frequently used in previous empirical research, it poses a number of practical and conceptual difficulties. Clearly, collecting the needed data is far from straighforward (Bhagwat and Berg, 1992). In practice this has been done employing user surveys, thus giving rise to the standard problems associated with obtaining reliable and relevant answers to the research questions posed. Some studies also employ different types of revealed preference approaches, thus making use of variations across time and/or over users in the availability of information. Bernknopf et al. (1997, 2007) instead explicitly model improved decision-making following the use of geological information with higher-quality, e.g., investigating the value of improved mineral exploration efficiency by comparing the impacts of improved information to a baseline scenario with existing information.

Results and lessons from previous empirical research

Our review of previous research studies on the economic value of geological information (including other types of earth observations) is summarized in Table 1. It shows that overall there appear to be significant economic benefits attached to the generation of this type of public information. Most studies show favorable benefit-cost ratios, and the resulting benefits affect a number of different users. However, the methodologies used differ across studies, as do important assumptions on sectors evaluated as well as on discount rates. In the remainder of this section we synthesize this research, primarily focusing on some important methodological challenges and choices. In order to provide a template for the literature synthesis, we have organized this research into the following categories: (a) existing studies addressing aggregate data on expenses and turnover of geological information or other geodata services (Input-based assessments using expense and cost data); (b) research explicitly addressing – often through the use of survey-based or revealed-preference approaches – the economic value of geological information (The avoided costs and improved decision-making of geological map use); and (c) related valuation studies addressing the economic value of either other types of earth observations or spatial data infrastructures (Assessments of other earth observations and related SDI).

Input-based assessments using expense and cost data

Some previous studies on the economic importance of geological information are government and consultancy reports addressing not so much the societal value of such information, but rather the turnover (i.e., market size) of related products and services (e.g., geological maps), and/or the costs of providing these products. Thus, while it is useful to provide a brief review of such work it should be noted that these studies do generally not build on an appropriate theoretical notion of economic value. Another important feature of this category of studies is that they primarily focus on aggregate – rather than marginal – values. In spite of this, though, some of these studies offer a decent description of the size of the markets related to geological information.

Examples of this type of work include Ovadia (2007) and Roger Tym and Partners (2003), which both assess the economic value of geological information by identifying rough indicators of the products and services provided by geological surveys. Specifically, the reports assess the total expenses of the relevant geological surveys, and/or present estimates of the total value of all goods and services produced by the surveys. Roger Tym and Partners (2003) use the value-added method described by OXERA (1999). Frank (2001) also employs the OXERA approach, and uses this to conduct a cost-benefit analysis of the topographic survey in Austria. An important exception, though, is that Frank assesses the economic contribution of this information in terms of VAT (value added tax) revenues.

Input-based approaches provide only limited and arguably biased assessments of the real economic value of geological information or other earth based observations. Such studies assume that geological information is efficiently priced in the market place, and they therefore ignore important public good characteristics, which may include important spillover effects. Hence, the aggregate market value of a product, such as geological maps, will provide an underestimation of the total benefits by ignoring the size of the total consumer surplus.

Table 1
Previous research on the value of geological information and other earth observations.

	Study	Case and method	Results	Benefit-cost ratio
Input-based assessments	OXERA (1999)	Investigates the use of topographic data in the production of other goods. Based on customer interviews.	In 1996 the Ordnance Survey contributed to 12–20% of gross valued added in several sectors (e.g. utilities, local government and transport).	n.a.
	Frank (2001)	Analyses the value of the topographic survey activities in Austria.	In 2000 the topographic data contributed EUR 1100 million to private sector activities. This represented 6–12% of the Austrian gross valued added.	318:1
	Roger Tym and Partners (2003)	Uses a value-added method by identifying rough indicators of the products and services provided by the British Geological Survey (BGS).	The total benefit considerably exceeds the turnover. In 2001 the BGS contributed GBP 34–61 billion, representing 5–8% of the total UK output.	0.8–1.5:1
	Ovadia (2007)	Examines the contribution to national economies attributable to the geosciences. Based on literature review.	There exist clear benefits from geological information. Raises the question if future investments in geological information would maintain a high net benefit.	100–1000:1
Avoided cost approaches of geological information	Cressman and Noger (1981)	Evaluates the Kentucky Geological Survey, 1960–1978 (e.g. mineral commodities, engineering geology, environmental geology, land use etc.).	The geological information creates benefits, and can result in saving taxpayers' money on the application of government services.	n.a.
	Cocking (1992)	Evaluation of an aid-funded geological mapping project in Kenya. Assesses the geological data collection costs avoided by different enterprises.	Users placed a value on the costs that would have been incurred by their operations had the maps and reports not been available. A net benefit of more than GBP 0.2 million per year is reported in the study.	n.a.
	Bhagwat and Berg (1991, 1992)	Assesses the geological mapping in the state of Illinois based on Bone and Winnebago counties in the case of groundwater contamination risks.	The results strongly support the economic feasibility of geologic mapping programs that are used to support the environmental planning process.	1.2–2.7:1
	Bernknopf et al. (1993, 1997)	Estimates cost savings attributed to the use of a new map for two regulatory cases: a landfill (contamination) and the Washington Bypass (construction).	The authors report annual net benefits of USD 1.28–3.50 million (1993 price level).	2–4:1
	Ellison and Calow (1996)	Assesses the impacts of information gained through geological mapping projects in the UK (including a case study from a local re-mapping).	The estimated net benefits of the re-mapping application was GBP 0.54 million. For the anecdotal national remapping program a baseline net value was estimated at GBP 15.7 million.	n.a.
	Bhagwat and Ipe (2000)	Estimates the economic benefits of the entire geological mapping program of the state of Kentucky.	Based on survey results of avoided costs the authors estimated savings of USD 2.2–3.5 billion.	17–28:1
	Reedman et al. (2002)	Estimates water supply development costs with and without the information provided by hydrological information in Nigeria.	Estimated savings in borehole-drilling costs of GBP 751000 (1996 price level) for the time period 1996–2006.	3:1
	Scott et al. (2002)	Assessment of the value of a regional geological mapping program for mineral exploration purposes in Australia.	The authors use a revealed preference approach and report an annual net benefit of AUD 4.3 million for mineral exploration.	n.a.
	Garica-Cortés et al. (2005)	Assessment of the economic benefits of the so-called MAGNA sheets (the national geological maps of Spain).	The authors estimate net benefits of EUR 1.25–3.34 million for the geological mapping program based on the costs avoided.	10–27:1
	Bernknopf et al. (2007)	Analysis of improved government geological map information for mineral exploration efficiency in Canada (two case studies).	Both cases indicate that the improved mapping implied increases in expected targets and a reduction in search efforts (efficiency). In one of the cases the net benefits of an updated map are estimated at CAD 0.4–13.4 million.	1–13:1
Other earth observations and related spatial data infrastructure (SDI)	Price Waterhouse Coopers (1995)	Benefit assessment of SDI in Australia based on surveys.	For the time period 1989–1994 land and geographic information data generated benefits of AUD 4.5 billion to the Australian economy.	4:1
	PIRA (2000)	Public sector information in Europe (geographical information).	Value added from geographical information of EUR 36 billion per year.	n.a.
	Dufourmont (2004)	Extended impact assessment of infrastructure for spatial information in Europe (INSPIRE).	The benefits outweigh the investment requirements by a considerable amount, with an annual net benefit of EUR 36 million.	n.a.
	Halsing et al. (2004)	Simulating the costs and benefits of the U.S. Geological Survey's national mapping program.	Net benefits estimated at USD 1–3 billion. The break-even point is after 14 years, due to high upfront cost while benefits accumulate over the years.	n.a.
	Booz Allen Hamilton (2005)	Assessing the return on investment of geospatial interoperability at NASA.	Risk-adjusted ROI of 119 % indicating that for every USD invested, USD 1,19 is saved on operations and maintenance costs.	n.a.
	ACIL-Tasman (2008)	Impact assessment of SDI technologies on the Australian economy.	In 2006–2007, the spatial information contributed to a cumulative gain of AUD 6.43–12.57 billion (equivalent to 0.6–1.2% of the Australian GDP).	n.a.
	ACIL-Tasman (2009)	Assesses productivity gains from the use of spatial information in New Zealand.	In 2008, the use and re-use of spatial information added NZD 1.2 billion in product-related benefits. An additional NZD 481 million could have been realized if existing barriers to use had been removed.	5:1
	Bouma et al. (2009)	Assesses the value of geoinformation for water quality management in the North Sea (e.g. observing algal blooming).	The authors report that the satellite geoinformation provided annual net benefits of EUR 0.24 million in the case of water management.	1.48:1
	Castelein et al. (2010)	Assesses the economic value of the Dutch geo-information (mainly using turnover data).	The estimated value of the Dutch geo-information sector was estimated at EUR 1.4 billion, which corresponds to about 0.25 % of the Dutch GDP.	n.a.
				n.a.

Table 1 (*continued*)

	Study	Case and method	Results	Benefit-cost ratio
Other earth observations and related spatial data infrastructure (SDI)	Craglia and Campagna (2010, 2012)	The economic impacts of the European INSPIRE geoportal, with a focus on regional cases (e.g., Lombardy).	The tangible economic benefits are significantly greater than the investment costs, with an average economic cost savings at EUR 3 million per annnum in the Lombardy case study.	n.a.
	Booz Allen Hamilton (2013)	Impact analyses on the socioeconomic benefits of earth observation; case study of volcanic ash advisories and aviation safety.	The data saved USD 24–72 million in avoided revenue losses due to unnecessary delays and avoided aircraft damage costs.	n.a.
	Miller et al. (2013)	Assesses the value of the US Landsat, moderate-resolution satellite imagery in the USA, using *WTP* estimates.	The authors estimate a total annual benefit of USD 2.0–2.2 billion from the Landsat imagery, however not including benefits from the reuse of the imagery.	

Note: EUR=Euro, USD=United States Dollars, AUD= Australian Dollars, NZD= New Zealand Dollars, CAD=Canadian Dollars, and GBP=Pound sterling.

Overall these studies fail in addressing the full economic value of geological information due to the significant difficulties associated with defining and valuing the benefits of activities that generate public information. Achieving this purpose directly through the value of marketable goods and services represents a biased approach.

These difficulties are also connected to the fact that geological information are usually not the final products or services but rather inputs into other planning processes (Scott et al., 2002). Hence, it may not be appropriate to assign values to the geological information alone, separating it from the value of the service delivering the data.[6]

The avoided costs and improved decision-making of geological map use

Most empirical work assessing the economic benefits of geological information focuses on the avoided costs and improved decision-making (e.g., in terms of higher productivity or reduced uncertainty) of having access to information compared to the cases where such information is not available.

One of the first studies with this scope was Cressman and Noger (1981), and later followed by Bhagwat and Berg (1992). However, the first rigorous economic treatment of the value of geological maps based on expected benefits and costs was outlined by Bernknopf et al. (1993, 1997). They focus on the regulatory decision-making process in the USA, and evaluate the role of improved geological information for permitting a particular land use in terms of threshold geological conditions. The value of the improved information is the net value of the economic and environmental losses avoided. The authors applied this approach to a contamination case (i.e., the location of a waste disposal facility), as well as the case of slope failure in the routing of a highway. For each of these cases the authors investigated the value of a marginal increase in the quality of geologic mapping.

Another important U.S. study is Bhagwat and Ipe (2000). The authors identify different activities that require geological maps, assess the importance of using such maps in projects undertaken, and estimate the economic value of these to the users. The economic benefits of improved geological information are assessed by calculating the avoided costs associated with not having to collect the needed information (in the absence of publicly available information). Specifically, a minimum value and a maximum value of this cost are assessed; the former asks for the amount the users would have been willing to spend to collect the information contained in the map while the latter asks for the amount of money saved because of the availability of the maps. By basing their results on nine possible elicited values the authors hope to reduce the bias that could otherwise arise from strategic behavior in revealing the respondents' subjective estimates.

The Bhagwat and Ipe (2000) approach has been used extensively in more recent work applied on geological mapping in other countries and regions.[7] Following the same approach Kleinhenz and associates (2011) estimate the economic benefits of the Ohio Geological Survey's products and services. The analysis is based on a user survey, roundtable discussions as well as one-on-one interviews with different industry experts. The results show that in the absence of the geological maps provided by the state of Ohio an average of 17 percent of the project costs would have had to be spent on own information gathering and research in order to gain the corresponding information through own efforts.

While the above studies address a wide variety of geological map users, another set of studies focus on the value of geological information in specific empirical contexts (e.g., Ellison and Calow, 1996; Reedman et al, 2002; Bernknopf et al., 2007). In Ellison and Calow (1996) land subsidence costs are estimated with and without the incorporation of new geohazard information. Reedman et al. (2002) estimate the water supply development costs with and without hydrogeological information. Scott et al. (2002) and Bernknopf et al. (2007) focus on the role of updated geological information in improving decision-making in the mineral extraction sector. In an attempt to estimate the societal value of upgraded geological information, Scott et al. (2002) rely on revealed preference monetary information on additional royalty revenues and investment. While this type of information may be indicative of the important economic role of geological information it may not explicitly address its value to society. In the added investment case it builds on the assumption that each additional dollar of exploration investment is economically efficient from society's point of view.

[6] Longhorn (2010) as well as Borzacchiello and Craglia (2011) discussed the value of geoinformation, and whether it is suitable to assess the value of one dataset or instead the value of the information product of which the dataset is part of. It is clear that this distinction is valid also in the case of geological information. This is further discussed in Discussion and directions for future research.

[7] The work by Garica-Cortés et al. (2005) is an apt example of this; these authors focus on the case of the so called MAGNA sheets in Spain (i.e., national geological maps). In similar measure Cocking (1992) conducted an *ex-post* survey of geological map users. In this work the benefits of such information is not based on the value of the avoided losses, but instead on the private costs of collecting the data had it not been publicly available.

Bernknopf et al. (2007) also address the issue of improved mineral exploration efficiency. However, they specify a model that converts the geological maps into likelihoods of a geological setting containing an exploration target. This approach permits minimizing the search areas in exploration, and maximizing the expected number of exploration targets. The value of upgraded geological information can then be derived by comparing optimal exploration campaigns to existing ones (or those defined in a baseline scenario). This analysis shows that the improved information provided more exploration options, reduced exploration risks, as well as improved efficiency and productivity.

Both Bernknopf et al. (1993, 1997) and Bhagwat and Ipe (2000) disregard the issue of discounting by assuming a zero real discount rate. Bhagwat and Ipe (2000) justify this by stating that it is within the recommended range for public investments and that knowledge does not diminish with time. Bhagwat and Berg (1992) and Reedman et al. (2002) on the other hand assume a 10 percent real discount rate following recommendations for public project evaluations.

Assessments of other earth observations and related SDI

The research on the economic value of geological information is similar to work on other types of earth observations (e.g., meteorological and topological information). Much of this latter work focuses specifically on the value of public investments in spatial data infrastructure (SDI) supplying such information. Since the methodological challenges in terms of benefit assessment are very similar to the work addressing geological information, it is useful to provide a brief review also of this work.

The research on this topic also employs a multitude of methods, and the literature includes work using aggregate economic indicators (e.g., Castelein et al. (2010) on the Dutch geoinformation sector using data on turnover and employment), stated-preference techniques (e.g., Bouma et al. (2009) on the benefits of satellite information for managing water quality in the North Sea), as well as the avoided costs and improved decision-making of having access to improved or more extended information (Price Waterhouse Coopers, 1995; Gillespie 2000; Halsing et al., 2004; Booz Allen Hamilton, 2005).

An early study by Gillespie (2000) employs a revealed preference approach to investigate the value of using GIS in different applications in the USA. Similar to Scott et al. (2002) the authors use econometric methods. Efficiency benefits result when a GIS is used to do a task previously done without access to a GIS, i.e., the same quality of output is produced but quicker and at a lower overall cost. The economic benefits of using GIS are thus derived from the extra cost of having to rely on non-GIS methods.

A similar approach based on avoided costs is adopted in Halsing et al. (2004), who conduct an *ex ante* estimation of the costs and benefits of the US national mapping program. The estimation of expected benefits is based on likely improvements in processing information, and the study takes into account the fact that the adoption of technology involves a time lag and that not all applications are needed in every place or in every year. Booz Allen Hamilton (2005) introduces a value measuring method to estimate the return on investment of geospatial interoperate initiatives at NASA.[8]

Miller et al. (2011) estimate the economic benefits of the US Landsat and other types of moderate-resolution (MR) satellite imagery in the USA. This study focuses on MR users, and the value of the information provided by US Landsat is assumed to be equal to what the individual users would pay for that information otherwise. This is equivalent to the low avoided cost approach outlined by Bhagwat and Ipe (2000). The net benefits, Miller et al. (2011) assert, depend on the uncertainty associated with the project in which the information will be used, the importance of the outcome of the project, the cost of using the information and the cost of an appropriate substitute. Miller et al. (2013) continued investigating the users, usage and benefits of the Landsat imagery, now with a slightly modified version of the survey previously used. For instance, the latter survey provided double bounded contingent valuation results whereas the first survey only gave singe-bounded results.

Discussion and directions for future research

Geological information can play a key role in addressing the challenges of sustainable development, such as land degradation and groundwater protection, and it can in this way contribute to improved decision-making processes. For this reason, it is important to assess whether improved information should be provided. We have noted that some studies, although labeled as benefit assessments, merely present indicators of the importance of those sectors using geological information and/or reproduce sales figures. These studies do thus not provide explicit information about the economic values attached to the information.

The more theoretically consistent studies are either based on user surveys investigating the self-reported avoided costs of having access to improved information or on revealed preference approaches addressing how the decision-making process has improved (e.g., become more efficient in terms of higher productivity in mineral exploration efforts). The empirical results from previous research indicate that overall significant economic benefits can be attached to the use of publicly available geological information. Nevertheless, our understanding of how to assess the benefits of investing in geological information is still limited. The academic research is scarce and there exist a need for comparisons of methods. In the remainder of this section we identify a number of important issues for future research and initiate a discussion of how these issues can – and should be – addressed.

One methodological challenge connected to the value assessment of geological information is that the information generates different benefits (and costs) depending on the context in which it is used. The literature ranges from studying specific decision-making processes (e.g., Bernknopf et al., 1997) to addressing the aggregated benefits of entire regions (e.g., Garica-Cortés et al., 2005), without problematizing how these different contexts affect the reliability and validity of these assessments. We therefore suggest that the issue of context-sensitive results is devoted increased attention in future research, and that clearer criteria could enable transparent benefit transfers.

The benefit transfer method is the adaptation of existing information to new contexts, e.g., estimating economic values of ecosystem services by transferring available information from studies already completed in another location. While the economic values of geological information typically are highly context-specific, it will remain too complicated to conduct explicit benefit assessments for each and every situation. In such situations we could instead draw on previous experiences in a systematic and transparent manner. The environmental economics literature has devoted a lot of attention to benefit-transfer and important lessons can be drawn from this work also in the case of valuing information. For instance, the literature expresses site correspondence as a necessary condition for benefit transfer

[8] Craglia and Novak (2006) identify Booz Allen Hamilton (2005) and Halsing et al. (2004) as examples of good methodological practice in the field. For instance, the valuation method outlined by Booz Allen Hamilton (2005) provides, it is argued, a useful structured framework to capture a wide range of benefits to several stakeholders.

(Smith et al., 2002; Loomis and Rosenberger, 2006; Johnston and Rosenberger, 2010). The underlying assumption is that similar quality sites will likely result in similar values per unit. Detailed information about the study sites is therefore necessary if transfer application should be made possible.

The access to primary studies data on geological information is today very limited, hence we suggest that a database with similar structure as, for instance, the so-called Environmental Value Reference Inventory (EVRI) should be considered. EVRI includes information about value assessments from a wide range of environmental goods. For each study there is information concerning references, area studied, method(s), variables included and a summary of the study. Increased access to prior collected data could also enable meta-analysis, which summarizes the results of existing studies by estimating statistical relationships between the values reported. This would capture the heterogeneity within and across studies and help identify the criteria needed form future benefit transfer studies.

Our review shows that survey-based methods (based on avoided costs assessments) are the most commonly used, but they are also complemented by other types of value-elicitation methods (e.g., simulation models, revealed preference approaches etc.). Some scholars argue that as of yet there has not been a convergence in terms of the reference methodology (e.g., Craglia and Novak, 2006), but this should not be interpreted as a case for not encouraging different types of methodological approaches. So far there is very little research involving systematic comparison of different methods, i.e., research where different methods are applied to the same case. For instance, by comparing the experiences expressed by companies in survey studies compared to the actual outcomes (revealed preference approaches) the assessments methods can be further scrutinized. We encourage such work as it could further clarify important strengths and weaknesses of the existing methods, and help improve these or even develop new ones. Brander and Koetse (2011) conducted two meta-analyses of contingent valuation and hedonic pricing results in the case of urban open space and found that the methodological differences in study design had a large influence on estimated values and that there existed important regional differences. Similar studies do not yet exist in the context of geological information.

Within the environmental economics field there is also growing literature on how one can combine methods to improve valuation models. For example Adamowicz et al. (1994) and Adamowicz et al. (1997) combined revealed and stated preference methods for valuing environmental public goods. Both articles found that once the heterogeneity of variance is accounted for, the joint models are superior. Whitehead et al. (2008) noted that the combination of such data can exploit the advantages of each data source while mitigating the problems associated with their respective weaknesses. Revealed preference estimations are, for instance, limited by the range of conditions to which the respondents can be exposed to as well as the multicollinearity issue. Stated preference data can mitigate these problems. Another advantage of a joint estimation is the increased efficiency of the estimation in terms of econometric efficiency, but also lower research costs since a smaller sample size is needed for the combined model.

Another methodological issue that is important to address in future research is to what extent it is meaningful to assign values to geological information as such, thus separating it from the services delivering the information. Arguably, the value is derived from the use of the information (i.e., service or decision-process) rather than from a specific data set. We argue that the quasi-public good qualities (e.g. non-rival but with licensing restrictions) of geological information should therefore be further examined by discussing the interoperability of this information with other statistical information sources. Our review indicates that more attention has been devoted to this question in the empirical context of other types of earth observations, and less so with respect to geological information.

Many studies acknowledge that while the investments in geological information are made upfront the benefits are typically generated over a certain time period, and therefore need to be discounted into a present value. The choice of an appropriate discount rate is an important issue in all cost-benefit analyses of public projects, and the case of geological information is no exception. Nevertheless, we do find significant differences in the assumptions made on the discount rate. These assumptions are within the 0–10 percent range. However, both of these end points are hard to motivate. A ten percent discount rate may be appropriate for private companies with relatively high rate-of-return requirements (e.g., due to higher risk-taking), but appears less motivated in the case of public investments in geological information. A zero discount rate also appears misleading for many reasons. First, it suggests that the social rate-of-return on alternative public investments – such as health care or education – is very low (zero), which is unlikely to be the case. In addition, from a consumption perspective the logical implication of zero discounting is the impoverishment of the current generation in favor of all future generations (e.g., Olsen and Bailey, 1981), which also could be questioned. The above shows that increased attention should be devoted to the appropriate choice of discount rate, and that neither zero percent nor ten percent discount rates are likely to be appropriate from a societal point of view.

Progressing from the specific methodological issues of benefit assessments, it should also be noted that these benefit assessments are conducted both *ex ante* and *ex post*. In the former case the assessment is made prior to investing while the latter case involves the evaluation of past investments. So far in this section we have focused on *ex post* assessments. Clearly, the *ex ante* assessments can be biased due to unforeseen events whose effects can only be comprehended *ex post*. In this paper we argue that geological information should be considered an experience good. Given this it could be difficult for, in particular, potential users to assess the avoided costs of using geological information. The users will therefore also find it difficult to *ex ante* assess the need for – and the value of – putting in more effort in collecting information. Since the users are often not aware of the value before the information is available it could lead to underestimations *ex ante* (see also Arrow, 1962; Brennan, 2012). Recalling the results reported by Bhagwat and Ipe (2000) that only 30 percent of the use of the geological maps in the state of Kentucky represented decision-making processes that initially justified the investment in these maps.

This carries at least two important implications for future research. First, while the estimated benefit-cost ratios could be biased *ex ante*, this could be evaluated in *ex post* assessments. So far such *ex post* verifications have been scarce, even though the literature has expressed a growing awareness of the need to conduct such retrospective assessments of the economic impacts of earth observations. By verifying prior *ex ante* assessments, the level of uncertainty experienced by public decision-makers may be reduced. Second, there is also a need for additional empirical research on the determinants of the adoption of geological information among different types of users.

ACIL-Tasman (2009) concludes that there is a tremendous potential for further societal benefits to be realized if existing barriers to adopt SDI were to be removed. Arguably, the same argument could be applied to geological information. If the geological information could be made more accessible and reach a wider audience, this could in turn lead to additional societal benefits. The population of existing and potential users is to a significant extent unknown, yet there have been few studies addressing this issue. We therefore suggest that future research could focus more on the heterogeneity among actors and on the factors that determine information adoption among users facing different goals and incentives.

Moreover, one could consider the adoption of new information as a process similar to those explained in the research literature on innovation. The rate of adopting information could then be perceived influenced by compatibility with prior conditions (e.g., previous practices and norms) and the complexity connected to adopting new information (e.g. new software or standards). Häggquist and Nilsson (2015) consider the adoption of geological information in Swedish municipalities. The authors estimate linear probability (LPM) and instrument variable generalized method of moment (IV-GMM) models of adoption, and find that personal beliefs and capabilities affect the rate of adoption. The results thus indicate that the models used in the innovation literature can be adapted to capture the adoption of geological information.

Conclusion

This paper has provided a review of empirical research on the economic value of geological information. The results from previous research indicate that significant economic benefits are attached to the use of geological information. Still, the methodological approaches differ and there is a need to understand more about the strengths and weakness of each of these. Specific attention should also be devoted to the use of discount rates, benefit-transfer approaches, and the relationship between geological information and the products that provide such information.

This paper argues that geological information have clear experience good qualities, which have been disregarded in the prior literature, but should have several implications for the societal value. First economic values assessed, *ex ante* may be underestimated and should be confirmed *ex post*. Second, the geological information is typically highly location and context dependent, and there may therefore exist significant market segmentations. Moreover, the use of geological information implies an initial knowledge threshold, i.e., a basic understanding to appropriate the benefits of this good, and the opportunity cost of learning-by-using will have a significant impact on demand. Finally, additional research is also suggested on the behavior of and the incentives faced by existing and potential users of geological information, and on the process of adopting new geological information.

Acknowledgments

Financial support from the Geological Survey of Sweden (SGU) is gratefully acknowledged (Grant no. 61-1451/2011), as are valuable comments on the paper from Susana Goytia Casermeiro, Jonas Grafström, Elin Spegel, Åsa Lindman, and one anonymous reviewer. Any remaining errors, however, reside solely with the authors.

References

ACIL-Tasman, 2008. The value of spatial information: the impact of modern spatial information technologies on the Australian economy. Prepared for the CRC for Spatial Information & ANZLIC – the Spatial Information Council, ANZLIC, Melbourne.
ACIL-Tasman, 2009. Spatial information in the New Zealand economy: realising productivity gains. Prepared for land information New Zealand, Department of Conservation; Ministry of Economic Development, Melbourne.
Adamowicz, W.L., Louviere, J., Williams, M., 1994. Combining stated and revealed preference methods for valuing environmental amenities. J. Environ. Econ. Manag. 26, 271–292.
Adamowicz, W.L., Swait, J., Boxall, P., Louviere, J., Williams, M., 1997. Perceptions versus objective measures of environmental quality in comined revealed and stated preference models of environmental valuation. J. Environ. Econ. Manag. 32, 65–84.
Andersson, D.E., Andersson, Å.E., 2013. The economic value of experience goods. In: Sundbo, J., Sørensen, F. (Eds.), Handbook on the Experience Economy. Edward Elgar Publishing Limited, Cheltenham, pp. 84–97.
Arrow, K., 1962. Economic welfare and the allocation of resources for invention. In: Nelson, R. (Ed.), The Rate and Direction of Inventive Activity. Princeton University Press, Princeton.
Berg, R.C., 2005. Societal and economic benefits of three-dimensional geological mapping for environmental protection at multiple scales: an overview perspective from Illinois, USA. In: Ostaficzuk, S. (Ed.), The Current Role of Geological Mapping in Geosciences. Springer, Netherlands.
Brander, L.M., Koetse, M.J., 2011. The value of urban open space: meta-analyses of contingent valuation and hedonic pricing results. J. Environ. Manag. 92, 2763–2773.
Brennan, T.J., 2012. Commentary: valuing information, ascertaining risk, and setting the target. In: Laxminarayan, R., Macauley, M.K. (Eds.), The Value of Information: Methodological Frontiers and New Applications in Environment and Health. Springer, London.
Bernknopf, R.L., Brookshire, D.S., McKee, M., Soller, D.R., 1993. Societal Value of Geologic Maps. U.S. Geological Survey, Virginia (Circular No. 1111).
Bernknopf, R.L., Brookshire, D.S., McKee, M., Soller, D.R., 1997. Estimating the social value of geologic map information: a regulatory application. J. Environ. Econ. Manag. 32 (2), 204–218.
Bernknopf, R.L., Wein, A.M., St-Onge, M.R., Lucas, S.B., 2007. Analysis of improved government geological map information for mineral exploration: incorporating efficiency, productivity, effectiveness, and risk consideration. Geological Survey of Canada, Bulletin No. 593, U.S. Geological Survey, Professional Paper No. 1721, Virginia.
Bhagwat, S.B., and Berg, R.C., 1991. Benefits and costs of geologic mapping programs in illinois: case study of boone and winnebago counties and its statewide applicability. Illinois State Geological Survey, Circular No. 549.
Bhagwat, S.B., Berg, R.C., 1992. Environmental benefits vs. cost of geologic mapping. Environ. Geol. Water Sci. 19 (1), 33–40.
Bhagwat, S.B., and Ipe, V.C., 2000. Economic benefits of detailed geologic mapping to Kentucky. Illinois State Geological Survey, Special Report No. 3.
Booz Allen Hamilton, 2005. Geospatial interoperability return on investment study. NASA, Geospatial Interoperability Office.
Booz Allen Hamilton, 2013. Measuring socioeconomic impacts of earth observations – a primer. NASA, The Earth Science Division, The Applied Sciences Program.
Borzacchiello, M.T., Craglia, M., 2011. Socio-economic benefits from the use of earth observation. Report from the International Workshop held at Joint Research Centre. European Commission Joint Research Centre, EUR 2495.
Bouma, J.A., van der Woerd, H., Kuik, O., 2009. Assessing the value of information for water quality management in the North Sea. J. Environ. Manag. 90 (2), 1280–1288.
Castelein, T.W., Bregt, A., Pluimers, Y., 2010. The economic value of the Dutch geoinformation sector. Int. J. Spat. Data Infrastruct. Res. 5, 58–76.
Champ, P.A., Bishop, R.C., 2006. Is willingness to pay for a public good sensitive to the elicitation format. Land Econ. 82 (2), 162–173.
Cocking, J., 1992. Synthesis of geological survey evaluations. Evaluation Department, Overseas Development Administration UK. Evaluation Report No. 542.
Craglia, M., Campagna, M., 2012. The socioeconomic impact of the spatial data infrastructure of Lombardy. Environ. Plan. B: Plan. Des. 39 (6), 1069–1083.
Craglia, M., Friedl, L., Pearlman, J., 2012. Quantifying the value of environmental information to society. EOS Trans. Am. Geophys. Union 93 (30), 291.
Craglia, M., Nowak, J., 2006. Assessing the impact of Spatial Data Infrastructures, Report of the International Workshop in Spatial Data Infrastructures' Cost-Benefit/ Return on Investment. European Comission, Joint Research Centre, EUR 22294.
Craglia, M., Pavanello, L., Smith, R.S., 2010. The use of spatial data for the preparation of environmental reports in Europe. European Commission Joint Research Centre, EUR 24327.
Cressman, E., Noger, M.C., 1981. Geologic mapping of Kentucky – a history and evaluation of the Kentucky geological survey – U.S. geological survey mapping program 1960–1978. U.S. Geological Survey, Circular No. 801, Virginia.
Ellison, R.A., Calow, R., 1996. The Economic Evaluation of BGS Geological Mapping in the UK, British Geological Survey.
Frank, A., 2001. The Surveying activities at the Austrian Federal Office for Metrology and Surveying: An Economic Analysis. Austrian Federal Ministry of Economics & Labour, Vienna.
Garica-Cortés, A., Vivancos, J., Fernández-Gianotti, J., 2005. Evaluación económica y social del Plan MAGNA. Bol. Geol. Min. 116 (4), 291–305.
Gillespie, S., 2000. An empirical approach to estimating GIS benefits. URISA 12 (1), 7–14.
Grant, D., Williamson, I., 1999. The Bathurst declaration on land administration for sustainable development. Fédération Internationale des Géomètres, FIG publication No. 21.
Halsing, D., Theissen, K., Bernknopf, R.L., 2004. A Cost-Benefit Analysis of The National Map. U.S. Geological Survey, Virginia (Circular No.1271).
Häggquist, E., Nilsson, I., 2015. The Adoption of Geological Information in Local Governments: The Case of Swedish Municipalities. Luleå University of Technology, Sweden (unpublished working paper).
Johnston, R.J., Rosenberger, R.S., 2010. Methods, trends and controversies in contemporary benefit transfer. J. Econ. Surv. 24 (3), 479–510.

Kleinhenz and associates, 2011. An Economic Impact Analysis of the Ohio Geological Survey's Products and Services. Ohio Geological Survey.
Krek, A., Frank, A., 2000. The economic value of geo information. J. Spat. Inf. Decis. Mak. 13 (3), 10–12.
Krek, A., 2002. An Agent-based Model for Quantifying the Economic Value of Geographic Information. Vienna University of Technology, Vienna University of Technology, Austria (Ph.D. dissertation).
Loomis, J.B., Rosenberger, R.S., 2006. Reducing barriers in future benefit transfers: Needed improvements in primary study design and reporting. Ecol. Econ. 60, 343–350.
Longhorn, R., 2010. Valuing the Invaluable: A Geoinformation Conundrum. Keynote at the GeoValue Workshop.
Macauley, M., Laxminarayan, R., 2010. The value of information: methodological frontiers and new applications for realizing social benefit workshop. Sp. Policy 26, 249–251.
Magesan, A., Turner, M.A., 2010. The value of information in regulation. B.E. J. Econ. Anal. Policy (Article 76).
Miller, H., Sexton, N.R., Koontz, L., Loomis, J., Koontz, S.R., Hermans, C., 2011. The users, uses, and value of landsat and other moderate-resolution satellite imagery in the United States. U.S. Geological Survey, Open-File Report No. 2011-1031, Virginia.
Miller, H., Richardson, L., Koontz, S.R., Loomis, J., Koontz, L., 2013. The Users, Uses, and Value of Landsat Satellite Imagery – Results from the 2012 Survey of Users. U.S. Geological Survey, Open-File Report No. 2013-1269.
Morrison, M., Brown, T.C., 2009. Testing the effectiveness of certainty scales, cheap talk, and dissonance-minimization in reducing hypothetical bias in contingent valuation studies. Environ. Resour. Econ. 44, 307–326.
Nelson, P., 1970. Information and consumer behavior. J. Polit. Econ. 78, 311–329.
Olsen, M., Bailey, M., 1981. Positive Time Preference. J. Polit. Econ. 89 (1), 1–25.
Ovadia, D., 2007. Geology as a contributor to national economies and their development. British Geological Survey.
Oxford Economic Research Associates Ltd., 1999. The Economic Contribution of the Ordinance Survey of Great Britain. OXERA, Oxford, United Kingdom.
Pira International Ltd., University of East Anglia and Knowledge View Ltd., 2000. Commercial Exploitation of Europe's Public Sector Information – Final Report. European Commission, Directorate-General for the Information Society, PIRA.
Price Waterhouse Coopers, 1995. ANZLIC Benefit Study, Australian and New Zealand Land Information Council. ANZLIC, Australia.
Reedman, A.J., Calow, R., Johnson, C.C., Piper, D.P., Bate, D.G., 2002. The value of geoscience information in less developed countries. British Geological Survey, Commissioned Report CR/02/087N.
Results Task Force XIA. In: Dufourmont, H. (Ed.), 2004.
Rodriguez-Pabon, O., 2005. Cadre Théorique Pour Lévaluation des Infrastructures d ´Information Géospatiale. (Ph.D. dissertation). Université Laval, Canada.
Roger Tym & Partners, 2003. The economic value of the BGS. British Geological Survey.
Scott, M., Dimitrakopoulos, R., Brown, R.P.C., 2002. Valuing regional geoscientific data acquisition programmes: addressing issues of quantification, uncertainty and risk. Nat. Resour. Forum 26, 55–68.
Smith, V.K., van Houtven, G., Pattanayak, S.K., 2002. Benefit transfer via preference calibration: "prudential algebra" for policy. Land Econ. 78, 132–152.
Stephan, P., 2005. Robert K Merton's perspective on priority and the provision of the public good knowledge. Scientometrics 60 (1), 81–87.
Stiglitz, J.E., 1999. Public Policy for a Knowledge Economy, Department for Trade and Industry. Center for Economic Policy Research, London.
Swedish Geological Survey, 2011. Annual Report 2011, Uppsala.
Swedish Geological Survey, 2012. Annual Report 2012, Uppsala.
Ting, L., 2002. Principles for an Integrated Land Administration System to Support Sustainable Development. (Ph.D. dissertation). University of Melbourne, Australia.
Whitehead, J.C., Pattanayak, S.K., Van Houtven, G.K., Gelso, B.R., 2008. Comsbining Revealed and stated preference data to estimate the nonmarket value of ecological services: an assessment of the state of the science. J. Econ. Surv. 22 (5), 872–908.