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A Meta-Analysis on the Return on Investment of Geospatial Data and Systems: A Multi-Country Perspective

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Abstract

The availability, quality and accessibility of Geographic Information (GI) have significant socio-economic and environmental benefits, but the collection and maintenance of GI require substantial investments. Cost-benefit assessments (CBAs) attempt to justify the costs of geospatial data investments, applying different methodologies and focusing on diverse areas. Therefore, the Returns on Investment (ROI) vary considerably across studies, regions and sectors. The objective of this study is to explain some of the variation in the average ROI of GI by conducting a meta-analysis of 82 cost-benefit assessments between 1994 and 2013. In a first step, CBAs are systematically reviewed and relevant information is extracted. Particular emphasis is given to investment conditions and study characteristics. In a second step, multivariate regression methods are used to assess the size, significance and direction of individual effects. The results suggest that regional factors have the largest impact on the profitability of GI. Returns in Australia and New Zealand, for example, are four times larger than in Europe. In addition, small-scale regional investments have a 2.5 times lower return than large-scale international investments. Overall, the expected benefits of GI investments are approximately 3.2 times larger than the costs.

1 Motivation

Geographic information and geospatial data are vital for the understanding, monitoring and assessment of environmental change, the impact of human activities and socio-economic feedback. Economic development, disaster management, humanitarian aid, food security and peace are only a few of the examples in which geographic information is critical for decision-makers and individuals. With a rising likelihood of severe climate change impacts (IPCC 2007) and associated environmental and economic changes, geospatial data has become even more valuable to society; and more accurate and timely information is needed in order to understand the effects of climate change and to develop adequate mitigation and adaptation

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responses. As a result, there is growing interest in the collection and provision of geospatial data. Meteorological and hydrological services have produced large and comprehensive databases for global temperature, precipitation, wind and other key geospatial variables. Yet databases are often decentralized, limit access to users, are based on different standards and differ in data quality. For this reason, an efficient and effective usage of geospatial data is impeded which can have direct implications for organizations as well as for overall economic performance. For example, labor costs can increase or labor productivity can decrease due to additional time required for data acquisition and processing. Therefore, data quality and accessibility need to be improved and more Spatial Data Infrastructures (SDIs), which connect metadata, users and tools more efficiently, need to be implemented.

Governments, private companies and international organization are increasingly aware of the economic benefits of geospatial data and related infrastructures. In 2005, the United Nations endorsed the establishment of SDIs to increase coherence in geospatial data management, because SDIs "provide an institutional and technical foundation of policies, interoperable standards and procedures that enable organizations and technologies to interact in a way that facilitates geospatial information discovery, evaluation and applications" (UN 2007). More recently, the Group on Earth Observations (GEO) has built the Global Earth Observation System of Systems (GEOSS) which seeks to analyze and define the requirements of users, acquire, maintain and process earth system observations, develop common data formats and foster collaboration between disciplines. The purpose is to connect decision-support tools (such as mathematical models or biophysical observatories) with end-users, to enhance the reuse of existing databases and applications. This way, GEOSS can assist in deriving new insights on geospatial information and in efficient decision-making.

However, collecting, providing and maintaining geospatial data, as well as building infrastructures, requires many resources and is often associated with extensive public expenditures. Large public investment projects need to be justified and clearly indicate that the benefits exceed the investment costs. Even though geospatial data are beneficial to various sectors and areas (e.g. environment, society, and economy), quantifying the benefits is very challenging. Beside direct and quantifiable benefits (e.g. time saving, efficiency gains), geospatial data also may generate indirect or unquantifiable benefits (e.g. improved air quality, increased biodiversity) which are difficult to evaluate economically. In addition, geoscientific information can have spillover effects and indirectly affect other areas and sectors. Covering the whole range of benefits in individual assessments is nearly impossible. As a result, cost-benefit assessments are not straightforward and need to account for the complexity of returns on GI and SDI investments.

There are a large number of studies assessing the benefits of geospatial data, but few of the assessments account for initial or continual investment costs (e.g. Craglia 2003; Longhorn and Blakemore 2008; Craglia and Campagna 2010; Borzacchiello and Craglia 2013). Moreover, the characteristics of previous assessments (e.g. methodology, metrics, temporal or spatial scale) as well as investment types vary greatly and therefore lack comparability. As a result, the benefit-cost (BC) ratio of GI differs greatly between assessments and thus gives little insight into the profitability of GI and SDI investments and the returns on public expenditures. In order to explain some of the variation of *BC* ratios as well as to obtain more reliable information on the profitability of GI and geospatial investments, this study systematically examines previous assessments and extracts relevant information. Subsequently, reasons for variations in the returns and profitability are examined by conducting a meta-analysis. The following section briefly introduces the cost-benefit-assessments on which the database for the meta-analysis was built. Section 3 describes the data and develops the meta-regression model. The results are discussed in Section 4 and the robustness of the results is presented in Section 5. The last section concludes the study.

2 Systematic Literature Review

Reviewing benefit assessments and building the database are the main challenges of this study. The data collection requirements are high, because the methodologies (e.g. Net Present Value, Return on Investment), the timescales (e.g. year, decade) and the regional scopes (e.g. community, country, international) vary greatly between assessments, and comparability needs to be ensured. In addition, the assessments differ in their thematic orientation and consider different ranges of benefits (e.g. quantifiable direct/unquantifiable indirect benefits) which increases heterogeneity. Most studies simply examine the benefits associated with available geographic information or established infrastructures, whereas only a few studies evaluate the complete investment chain taking into account the costs and the benefits of GI. In order to gain insights into the profitability of investments, the database needs to include information on both the costs and the benefits of GI investments.

Accordingly, this study is based on an extensive literature review aiming at a complete coverage of the literature including a range of different sources, i.e. peer-reviewed scientific journals, scientific reports, books and grey literature. From an initial search of several hundred references, more than 100 studies, ranging from 1968 to 2013, were collected and inserted into an online bibliography[1] and reviewed in more detail. All studies that contain information on both the benefits and the costs are summarized in Table 1 and provide the database for the meta-analysis. Table 1 contains 95 observations obtained from 49 studies. Some of these studies investigated costs and benefits for specific industries or a specific government sector. Other studies cover a range of sectors and regions. We retrieve information on study characteristics, and investment conditions as well as on the benefits and costs of GI to generate a Benefit-Cost (BC) ratio. Due to the great variation in *BC* ratios and in order to ensure the validity and reliability of the database, we conduct a multivariate outlier test and omit 13 observations. The final database, therefore, contains a total of 82 observations. The comparability of the studies is increased by applying appropriate estimation methods and controlling for the various characteristics of the studies and the investments.

The highest *BC* ratio can be found in the study of McKenzie (2009), indicating a pay-off ratio of 20€ for every 1€ spent on geospatial data.[2] A number of low *BC* ratios are also found, for example in Stewart (2008). A major concern of this meta-analysis is that the *BC* ratios may be biased upwards, because projects with financial losses are not likely to be reported or published. However, Stewart (2008) reports a number of very small returns on GI investments in Iowa and even calculates a negative return (–0.5:1) for the Indiana Geographic Information Council (IGIC). These findings reduce our concerns about a positive publication bias.

3 Data and Methodology

The main hypothesis of this article is that the variation in the average *BC* ratio can partly be explained by the study characteristics (e.g. methodological differences) and factors that exist beyond the study, such as the investment type or geographical characteristics. Accordingly, this study claims that the profitability of investments is not determined by any factor, but by a combination of different factors that need to be assessed simultaneously.

Table 1 Overview of geospatial data studies

Reference	Year	Region	Mean *BC* Ratio
Alessandro (2004)	2004	Europe	2.2
Alessandro (2004)	2004	Europe	0.88
Alessandro (2004)	2004	Europe	0.92
Almirall et al. (2008)*	2008	Europe	8.67
Applied GIS and ESRI (1995)	1995	US	2.04
Baltimore County (2001)	2001	US	1.42
Babinski et al. (2012)**	2012	US	10
Bernknopf et al. (2007)	2007	Canada	5.85
BCG (2012)**	2012	US	17.5
Borzacchiello and Craglia (2013)**	2012	Europe	10
Booz and Company (2011)	2011	Europe	3.7
Booz, Allen and Hamilton (2005)	2005	US	0.262
Bouma et al. (2009)	2009	Europe	0.67
CANRI (1999)	1999	Australia	1.82
Craglia (2003)	2003	Europe	6.65
Craglia (2003)	2003	Europe	6
Craglia and Campagna (2010)	2010	Europe	1.875
Craglia and Campagna (2010)	2010	Europe	1.733
Craglia et al. (2012)	2012	Europe	4
Dufourmont (2004)	2004	Europe	8.9
ESRI (2013)	2013	US	7
ESRI (2013)	2013	US	3
ESRI (2013)	2013	US	2.5
Fais and Bonati (1997)	1997	Europe	2.7
Foerster et al. (2005)	2005	Europe	4
Frank (2003)*	2003	Europe	23
Frei (2009)	2009	Europe	5
Gocht (2003)	2003	Europe	1.29
Gocht (2004)	2004	Europe	0.25
Guocai and Wang (2003)*	1994	China	37.5
GITA (2007)	2007	US	1.3
GITA (2007)	2007	US	1.3
GITA (2007)	2007	US	1.5
Gocht (2004)	2004	Europe	0.25
Gunasekera (2003)	2003	US	4.4
Korte (1996)	1996	US	4
KPMG (2001)	2001	Canada	4
Lazo et al. (2007)	2007	US	3
Lazo et al. (2009)	2009	US	6.2
Leviaekangas et al. (2007)	2007	Europe	6.5
Longhorn and Blakemore (2008)	2008	Australia	5.5
Longhorn and Blakemore (2008)	2008	Australia	5.9
Longhorn and Blakemore (2008)	2008	Australia	4.35

Table 1 Continued

Reference	Year	Region	Mean *BC* Ratio
Longhorn and Blakemore (2008)	2008	Australia	3.8
Longhorn and Blakemore (2008)	2008	Australia	2.7
Longhorn and Blakemore (2008)	2008	Australia	5.5
McKenzie (2009)**	2009	Australia	20
Merz and Gocht (2001)	2001	US	5.2
EC (2000)	2000	Europe	0.5
PwC (2006)	2006	Europe	6.28
PwC (1995)	1995	Australia	4
Rogers and Tsirkunov (2010)*	2008	Mozambique	70
Schroeter et al. (2006)	2006	Europe	5.8
Silva (1998)	1998	US	4
Stewart (2008)	2008	US	2.4
Stewart (2008)	2008	US	–0.5
Stewart (2008)	2008	US	0.66
Stewart (2008)	2008	US	1.74
Stewart (2008)	2008	US	1.7
Stewart (2008)*	2008	US	177.2
Stewart (2008)*	2008	US	56.028
Stewart (2008)*	2008	US	50.54
Stewart (2008)*	2008	US	30.31
Stewart (2008)	2008	US	2.3
Stewart (2008)	2008	US	5.7
Stewart (2008)	2008	US	1.1
Stewart (2008)	2008	US	7.4
Stewart (2008)*	2008	US	8.4
Stewart (2008)*	2008	US	73.1
Stewart (2008)*	2008	US	31.8
Stewart (2008)*	2008	US	34.9
Stewart (2008)*	2008	US	3635.3
Stewart (2008)**	2008	US	18.8
Stewart (2008)	2008	US	0.32
Stewart (2010a)	2010	Canada	2.1
Stewart (2010b)	2010	Canada	1.39
Stewart (2011a)	2011	Canada	2.2
Stewart (2011b)	2011	Canada	1.1
Stewart (2011b)	2011	Canada	2.1
Stewart (2011b)	2011	Canada	1.3
Stewart (2011b)	2011	Canada	0.34
Stewart (2011b)	2011	Canada	0.51
Stewart (2011c)	2011	Canada	11.81
Stewart (2011c)**	2011	Canada	5.4
Williamson (1994)	1994	Australia	2.75
World Bank (2008)	2008	Europe	0.5

Table 1 Continued

Reference	Year	Region	Mean *BC* Ratio
World Bank (2008)	2008	Europe	4.4
World Bank (2008)	2008	Eastern Europe	1.5
World Bank (2008)	2008	Eastern Europe	4.25
World Bank (2008)	2008	Eastern Europe	1.32
World Bank (2008)	2008	Eastern Europe	3.3
World Bank (2008)	2008	Eastern Europe	5.7
World Bank (2008)	2008	Eastern Europe	3.1
World Bank (2008)	2008	Eastern Europe	5
World Bank (2008)	2008	Eastern Europe	6.7

*Observations are omitted in final estimation in accordance with the Hadimvo multivariate outlier test
**Visually identified outlying observations

In order to develop the regression model and to select the appropriate estimation strategy, it is useful to examine the data in more detail. Table 2 presents the summary statistics of the 82 observations and focuses on: (1) investment characteristics; (2) the geographic location; (3) methodological features; (4) the assessment areas; and (5) organizational aspects.

Firstly, the average *BC* ratios and the distribution vary between the investment types. GI investments can have different impacts, ranging from regional (e.g. regional SDIs; Craglia and Campagna 2010) to international impacts (e.g. Rogers and Tsirkunov 2010). Studies that evaluate the returns of international investments are expected to be higher than for studies that evaluate national or regional investments, because international GI can address a larger number and wider range of potential data users. The summary statistics show that the average *BC* ratio is indeed higher for international investments (5.2:1) than for national (4.7:1) or regional ones (3.3:1). In addition, we distinguish two investment scales: geospatial data related investments (GI) and investments in spatial data infrastructures (SDIs). SDIs connect users, tools and models in more efficient and flexible ways and require complex software components. Most SDI studies are based on hypothetical assumptions or few experiences, and therefore, the benefits are yet unclear. Even though, most observations assess the costs and benefits of geospatial data (67), the average *BC* ratio does not differ notably between data and infrastructure investments.

Secondly, we are interested in the impacts of the geographic location on investments, because environmental, socio-economic or political conditions can alter the impact of GI. We categorize communities and countries into four large regions: Australia/New Zealand, Eastern Europe, Europe and North America. The number of observations as well as the average *BC* ratio differs greatly by region. Nearly half of the observations are taken from North America, followed by Europe and Eastern Europe where the average *BC* ratio is around 3.9:1. Significantly fewer observations are taken from Australia and New Zealand (10) where the average *BC* ratio is amongst the highest (5.6:1).[3]

Thirdly, we account for methodological differences and their influence on the *BC* ratio. Methodologies that discount future expected benefits, for example, could yield higher *BC* ratios than methods that calculate the return on investment. Therefore, we distinguish between three methodological approaches: cost-benefit assessments (CBA), Return on Investment (ROI), and other metrics. Most studies (33) simply compare the costs with quantifiable benefits in CBAs and have an average *BC* ratio of around 3.9:1. A large number of studies use

Table 2 Summary statistics of BC values by study characteristics

Category	Variables	Obs.	Mean	SD	Min	Max
Investment scope	Regional	38	3.28	3.94	–0.5	18.8
	National	33	4.71	4.03	0.25	20
	International	11	5.16	3.0	0.5	10
Investment scale	Infrastructure (SDI)	15	4.11	2.84	0.262	8.9
	GI data	67	4.14	4.09	–0.5	20
Regions	Australia and New Zealand	10	5.63	5.22	1.82	20
	Europe	24	3.94	2.90	0.25	10
	Eastern Europe	8	3.86	1.92	1.32	6.7
	North America	40	3.93	4.32	–0.5	18.8
Methodology	Cost-benefit-assessment	33	3.92	3.51	0.25	17.5
	ROI	18	4.47	5.02	–0.5	18.8
	Other[a]	51	4.12	4.06	–0.5	18.8
Variance of the *BC* Ratio	Variance > 0	19	5.93	3.50	1.29	17.5
	Variance = 0	59	3.76	3.91	–0.5	20
Valuation point	Ex-post	51	4.68	3.84	0.25	20
	Ex-ante	32	3.30	3.79	–0.5	18.8
Assessment focus	Environmental benefits	41	4.58	3.30	0.25	20
	Socio-economic benefits	8	2.82	2.65	0.26	8.7
	Organizational benefits	33	3.90	4.71	–0.5	18.8
Organization type	Private	10	6.88	6.61	0.5	20
	Public	63	3.66	3.37	–0.5	18.8
	Miscellaneous[b]	7	4.37	2.28	0.67	7
Funding	Private	10	3.84	5.15	0.34	17.5
	Public	33	4.38	4.71	–0.5	20
	Miscellaneous[b]	39	4.0	2.64	0.25	11.8
	Total	82	4.13	3.88	–0.5	20

[a] Other methodologies use VMM, NPV, IRR, VOI or VA methods (as listed in the text below) or calculate the cost savings
[b] Miscellaneous presents a mix of public and private funding or several executing organizations

ROI methods (18) and have a slightly larger average *BC* ratio of 4.5:1. The remaining studies (51) use other metrics (e.g. Value Measuring Methodology, Net Present Value, Internal Rate of Return, Value of Information, or Value Added) or do not give any information about the underlying metric. The average *BC* ratio of studies using other metrics is 4.1:1. To account for uncertainty, we create a variance variable, which takes on the value of one if the study includes a range of *BC* ratios (e.g. minimum and maximum), and zero otherwise. Most of the studies with a range of *BC* ratios are model or theory-based, and therefore, the actual return remains uncertain. Other studies account for uncertainty in the estimation, for example, due to unquantifiable benefits or take into account future benefits. Studies that involve risk and uncertainty in the profitability of GI investments have a significantly higher average *BC* ratio (5.9:1) than studies with a definite *BC* ratio (3.8:1). Lastly, we add a variable that indicates whether the assessment is conducted before realization of the investment (ex-ante) or after realization (ex-post). This can give insights into possible discrepancies of expectations and realizations of returns on GI investments. Ex-post assessments have a higher average *BC* ratio (4.7:1) than ex-ante assessments (3.3:1).

Fourthly, the *BC* ratio can be higher or lower, depending on whether the assessment focuses on environmental, economic or organizational benefits. For example, a farmer may have higher benefits, using GI to determine the optimal harvest time, from an organization that saves time through improved data access. Most assessments focus on benefits for the environment (41), such as agriculture, water, weather and climate, whereas other studies assess organizational benefits (33), such as time savings or productivity gains. Only a few studies account for possible socio-economic benefits (8), such as health or civil protection. Environmental benefits (e.g. improved air quality) are often more difficult to quantify than organizational or socio-economic benefits (e.g. time saving). The average *BC* ratio is amongst the highest (5:1) for environmental assessments, followed by organizational assessments (4:1) and socio-economic assessments (3:1). The different average *BC* ratios suggest that there are sectoral differences, which need to be accounted for in the model.

Lastly, we distinguish between private and public organizations. Publicly and privately funded and implemented investments are expected to affect the profitability of GI investments due to differing strategies, efficiency, total investment cost or accessibility policies. The summary statistics indicate higher *BC* ratios for private organizations (6.9:1) than for public organizations (3.7:1), although publicly funded projects indicate slightly higher *BC* ratios (4.4:1) than privately funded investments (3.8:1). Some investments are funded and implemented in cooperation with private and public organizations. Hence, the average *BC* ratio of investments of public-private partnerships lies between the *BC* ratio of private and public organizations.

Overall, the average *BC* ratio is 4:1 and the database is very heterogeneous. Even though a ratio of 4:1 can be often found in the literature (e.g. PwC 1995), this value only presents an average and does not give any insights into the determinants of the profitability of GI investments (e.g. investment environment) or the significance of study characteristics or investment conditions. Therefore, a multivariate regression model is needed, which allows for the estimation of the combined effects of various study characteristics and for an examination of the significance of individual factors. The model is specified as follows:

$$BC_i = \alpha + \beta_s X_{is} + \beta_g X_{ig} + \beta_e X_{ie} + \varepsilon_i \tag{1}$$

where BC_i is the *i*th observation of the dependent variable *BC* (ratio of benefits to costs of geospatial and SDI investments as a measure of profitability). α is a constant and X_{is}, X_{ig} and X_{ie} are matrices of explanatory variables, containing study characteristics *s*, geographical characteristics *g* and investment characteristics *e*. The corresponding parameters to be estimated are represented by β_s, β_g and β_e. ε_i is the *i*th error term or the remaining disturbance. We are particularly interested in a consistent estimation of the parameters β_s, β_g and β_e in order to explain variation in *BC*. This requires that β_s, β_g and β_e are orthogonal to unobserved determinants of BC_i. In order to ensure orthogonality and a consistent estimation of the β parameters we first graphically investigate the distribution of BC_i across time and space.

Figure 1 shows the distribution of *BC* ratios across time. Fitting a simple linear trend, we find that the *BC* ratio averages around 4:1 to 3:1, with higher ratios in the 1990s and lower ratios in more recent years. In addition, the 95% confidence intervall of the linear trend indicates that there is more uncertainty about the average *BC* ratio in the 1990s than in recent years. Accordingly, when estimating the β parameters, we need to account for the temporal variation and therefore add a time trend to the regression model.

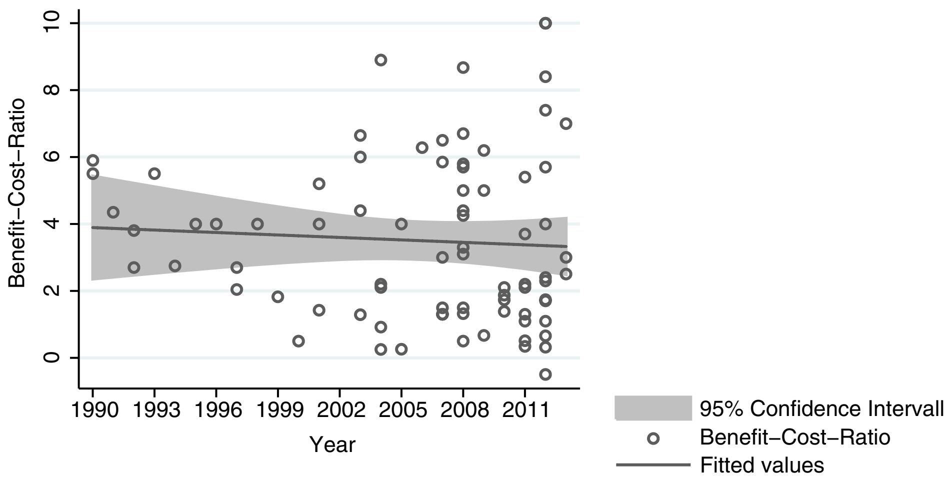

Figure 1 Distribution of the average Benefit-Cost-Ratio between 1994 and 2013
Source: Own elaboration based on meta-database

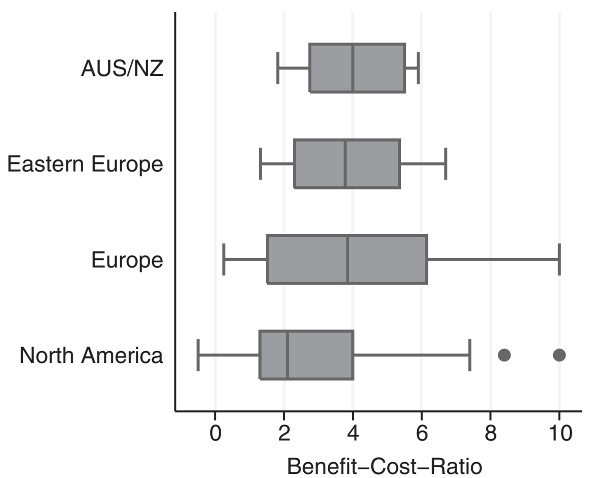

Figure 2 Distribution of the average Benefit-Cost-Ratio by region
Source: Own elaboration based on meta-database

Furthermore, we expect the *BC* ratios to vary regionally. Regions differ in their infrastructure, socio-economic or political environments which can influence investments positively or negatively. The distribution of *BC* ratios across the four main regions is shown in Figure 2. Although, the median *BC* ratios are around 4:1 in most regions, the median *BC* ratio in North America is significantly lower (>2:1). In addition, North America shows two observations that are outside the upper adjacent, which are omitted in the final estimation. The 75th and 25th percentiles of the *BC* ratios also differ significantly between the regions. While Europe has amongst the highest *BC* ratios and dispersion, Australia and New Zealand have a significantly smaller dispersion. Part of the regional variation may be due to the differing number of observations. Therefore, it is of particular importance to control for regions and regional characteristics.

As a means of the relatively small sample size and the heterogeneity of the studies, special attention needs to be paid to the estimation strategy. On the one hand, it is unclear which variables have significant influence on the *BC* ratio and should be included. On the other hand, omitted variables could bias the results and indicate significance of variables that are correlated with omitted variables. Therefore, we use a step-wise multivariate regression analysis to assess the impact of the relevant factors simultaneously and to examine the significance of the relevant factors. This approach can also indicate the sensitivity of the model and the robustness of the parameters of interest. We start with a reduced form:

$$BC_i = \alpha + \beta_1 \text{Variance} + \varepsilon_i \tag{2}$$

and successively extend the model based on the largest correlation between the covariates and the remaining residual and obtain a multivariate model as follows:

$$\begin{aligned} BC_i = \alpha &+ \beta_1\text{Variance} + \beta_2\text{Ex-post} + \beta_3\text{Regional} + \beta_4\text{National} + \beta_5\text{Eastern Europe} \\ &+ \beta_6\text{North America} + \beta_7\text{Australia\&NZ} + \beta_8\text{Socio-economic} + \beta_9\text{Organisation} \\ &+ \beta_{10}\text{SDI} + \beta_{11}\text{t} + \beta_{12}\text{Private Funding} + \beta_{13}\text{Misc. Funding} + \beta_{14}\text{CBA} + \beta_{15}\text{ROI} \\ &+ \beta_{16}\text{Private Organisation} + \beta_{16}\text{Misc. Organisation} + \varepsilon_i. \end{aligned} \tag{3}$$

In accordance with the results of the Box-Cox regression, we estimate the *BC* ratios in linear terms.[4] Heteroscedasticity (e.g. intra-study effects due to similar methodologies) poses additional methodological challenges that have to be accounted for in order to get reliable and consistent parameter estimates. We perform the Breusch-Pagan and Cook-Weisberg tests for heteroscedasticity in the error distribution (Breusch and Pagan 1979; Cook and Weisberg 1983). The Cook-Weisberg test rejects the null hypothesis of homoscedasticity, whereas the BPLM test does not reject the null hypothesis of homoscedasticity at the 1% level. We use Huber-White robust standard errors to mitigate heteroscedasticity. Another concern in our estimation is multicollinearity, which can lead to large changes in the coefficients and hence reduce the significance of affected variables. We examine the correlation coefficients of paired covariates by regressing selected variables on the remaining error. The results indicate that the variables have no impact on other variances, thus, the null hypothesis of multicollinearity is rejected. Lastly, due to the small sample size the reliability and robustness of the results need to be demonstrated and confirmed. The robustness checks are conducted in Section 5.

4 Results and Discussion

We use a least squares dummy variable regression in order to investigate sources of heterogeneity in the *BC* ratios and to assess the partial effect of several factors influencing the variation in the *BC* ratio of the investment. The results are presented in Table 3 and indicate that most variables have a significant impact on the *BC* ratio, but differ largely in their size and direction.[5] Various combinations of variables are tested and the model with the best statistical fit is identified applying the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) which measure the relative goodness-of-fit of the model. The results of both, the AIC and BIC, suggest that model (8) is the preferred model specification (cf. Table 4). Therefore, the discussion of the results refers to model (8).

Table 3 Regression results of the *BC*-Ratio

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Variance > 0	0.472***	0.479***	0.379***	0.448***	0.437***	0.433***	0.461***	0.477***	0.469***	0.457***
	(0.0867)	(0.0737)	(0.101)	(0.105)	(0.101)	(0.0973)	(0.0857)	(0.0837)	(0.0840)	(0.0866)
Ex-Post		1.144***	0.835*	1.119***	1.154***	0.971**	1.018**	1.178***	1.070**	1.067**
		(0.424)	(0.421)	(0.417)	(0.401)	(0.434)	(0.428)	(0.383)	(0.410)	(0.417)
Regional			–1.346*	–2.119***	–1.945**	–1.981***	–2.315***	–2.550***	–2.746***	–2.772***
			(0.803)	(0.753)	(0.785)	(0.709)	(0.687)	(0.609)	(0.594)	(0.627)
National			–0.235	–1.153	–1.048	–1.027	–0.782	–0.999*	–0.964	–0.950
			(0.733)	(0.746)	(0.729)	(0.670)	(0.654)	(0.587)	(0.614)	(0.626)
Eastern Europe				1.355	1.158	1.610*	1.360	0.932	1.032	1.051
				(0.917)	(0.918)	(0.949)	(0.925)	(0.923)	(0.947)	(0.982)
North America				1.450***	1.717***	2.113***	2.262***	2.470***	2.203***	2.188***
				(0.478)	(0.494)	(0.661)	(0.609)	(0.528)	(0.558)	(0.555)
Australia & NZ				1.411*	1.444*	1.768**	3.180***	4.202***	3.854***	3.853***
				(0.719)	(0.736)	(0.724)	(0.916)	(0.892)	(0.916)	(0.919)
Socio-economic					–1.465**	–1.594**	–1.816**	–1.959***	–2.057***	–2.022**
					(0.629)	(0.719)	(0.756)	(0.712)	(0.768)	(0.812)
Organiz-ational					–0.383	–0.495	–0.528	–0.479	–0.498	–0.444
					(0.518)	(0.555)	(0.478)	(0.425)	(0.401)	(0.465)
SDI & GEOSS						0.889	1.222*	1.364*	1.557**	1.596**
						(0.707)	(0.665)	(0.682)	(0.659)	(0.691)
Time trend							0.112**	0.161***	0.139***	0.137***
							(0.0464)	(0.0419)	(0.0398)	(0.0412)
Private funding								0.242	0.608	0.676
								(0.634)	(0.616)	(0.622)
Miscellaneous funding								1.012**	1.276***	1.294***
								(0.440)	(0.462)	(0.471)
CBA									0.327	0.294
									(0.422)	(0.423)
ROI									1.085	1.126
									(0.811)	(0.839)
Private organization										0.0122
										(0.5959
Miscellaneous organization										0.318
										(0.555)
Constant	2.681***	2.116***	3.056***	2.538***	2.595***	2.304***	0.143	–1.321	–1.192	–1.216
	(0.253)	(0.339)	(0.791)	(0.752)	(0.711)	(0.733)	(1.121)	(1.089)	(1.077)	(1.089)
Observations	74	74	74	74	74	74	74	74	74	74
R-squared	0.238	0.308	0.368	0.421	0.450	0.467	0.499	0.533	0.544	0.545
Cook-Weisberg	P = 0.45	P = 0.16	P = 0.67	P = 0.93	P = 0.88	P = 0.91	P = 0.80	P = 0.92	P = 0.74	P = 0.71
Breusch-Pagan	P = 0.01	P = 0.01	P = 0.00	P = 0.02	P = 0.05	P = 0.14	P = 0.14	P = 0.15	P = 0.12	P = 0.09

Note: Huber-White robust standard errors in parentheses, ***significant at the 1% level, **significant at the 5% level, *significant at the 10%level

The *BC* ratios are mainly influenced by regional factors. The four regions, i.e. Europe, Eastern Europe, North America, and Australia and New Zealand, differ economically, legally, technically, politically, and socially, and in their climatic conditions. The regional impacts on the *BC* ratio differ significantly. In North America the *BC* ratio is 2.5 times higher than in Europe, whereas in Australia and New Zealand it is 4.2 times higher than in Europe, holding all other variables constant. The difference between Europe and Eastern Europe is not significant, suggesting that the returns are similar in those regions. However, we cannot draw clear conclusions on the grounds of the substantial regional differences. It is conceivable that

Table 4 Model selection

Model	df	AIC	BIC
(1)	2	307.0311	311.6392
(2)	3	301.8206	308.7328
(3)	5	299.2134	310.7337
(4)	8	298.7389	317.1714
(5)	10	298.832	321.8726
(6)	11	298.5465	323.8912
(7)	12	295.9948	323.6436
(8)	13	294.8311	327.088
(9)	15	301.1077	335.6687
(10)	16	303.0426	339.9076

environmental or climatic conditions increase the benefits of GI, especially in Australia and New Zealand and the US where extreme weather events (e.g. droughts, fires, hurricanes) occur more regularly and on a larger scale than, for example, in Europe. Detailed geospatial information contributes to disaster and risk management practices, and thus reduces damages and losses. On the other hand, additional benefits could arise in the US and Australia due to social differences (e.g. number of data users), legal differences (e.g. data accessibility, confidentiality rules), technical differences (e.g. Internet access per capita), economic differences (e.g. infrastructure, income) or political differences (e.g. information, public expenditure on research). Therefore, more information is needed in benefit assessments that take into account data policies, user characteristics or the general socio-economic environment. Assessing the necessary framework conditions would help to identify the major barriers and obstacles in other regions (e.g. Europe) and to improve the investment environment and benefits of GI.

Furthermore, we find a large significant difference between the investment scopes. Compared with international investments, regional investments have a 2.6 times lower *BC* ratio, whereas national investments have a one times lower *BC* ratio than international investments. Regional investments are bound to specific regions, and therefore, only regional data users benefit from the investment and development is often bound to the specific region. International investments, on the other hand, include a larger number of users and regions which can result in higher returns. In addition, international investments often involve large-scale projects, which can harness synergies (e.g. joint working with shared costs and benefits), exploit economies of scale (e.g. development and implementation) or have positive spillover effects (e.g. development and sharing of best practice). Accordingly, the benefits are expected to be higher for international investments and the costs of international projects can be shared. Nevertheless, further investigation is needed on the difference between regional, national and international investments. For example, regional investments may have more unquantifiable benefits related to better data quality or data more customized to the needs of specific regions or users.

Most studies assess the benefits of implemented investments, but a few studies, especially assessments for SDIs, assess the benefits ex-ante based on theoretical assumptions or using the limited data and experiences available. Estimating both benefits and costs of ex-ante assessments is especially difficult and challenging, because ex-ante assessments are based on a number of ex-ante assumptions and theories which increase the complexity of the assessment. In particular, selecting the appropriate discount rate for discounting expected economic flows of future GI benefits is not straightforward. In addition, risk and uncertainty need to be factored into the assessment by adjusting the discount rate. The results suggest that the *BC* ratio of ex-post assessments is 1.2 times higher than that of ex-ante assessments. It is not clear why the *BC* ratios of ex-post and ex-ante assessments differ, but it is conceivable that the returns of ex-ante assessments are more conservatively estimated due to the choice of the discount rate or the inclusion of risk and uncertainty. Moreover, geospatial data can have multiplier effects and spillovers to other economic sectors (e.g. societal or environmental benefits) that may not be foreseeable and excluded from ex-ante assessments, whereas ex-post assessments often include benefits beyond the direct benefits.

Even though the average *BC* ratio for GI and SDIs does not differ (cf. Table 2), the results show that the *BC* ratio of investments in SDIs is 1.4 times higher than that of investments into geospatial information. SDIs connect users by building an infrastructure for GI and providing data, maps and tools in a more efficient and flexible way. This allows for a wider distribution of data and increased data access, as well as access to map and data services. Policy makers, researchers and individuals have ready access to geographic information and can examine trends and patterns to support economic, social or environmental development and assist in decision-making. As a consequence, the number of end-users and the resulting benefits can be considerably increased whereas the costs of data acquisition and maintenance can be shared.

Most benefit assessments have an environmental focus (e.g. weather, climate, soil or water quality). Only a few assessments have a socio-economic (e.g. transport, health, population) or organizational focus (e.g. time savings, efficiency gains). The results show that socio-economic assessments have a twice lower *BC* ratio than assessments with an environmental focus, suggesting that neglecting environmental benefits may undermine the benefits of GI investments. Furthermore, investments aiming at the environmental sector may have higher returns or lower costs than investments aiming at socio-economic sectors. The difference between organizational and environmental assessments, however, is not significant suggesting similar *BC* ratios for environmental and organizational assessments and investments.

Some studies consider a range of possible benefits (Variance > 0) whereas other studies determine a definite *BC* ratio. The latter restrict the assessment to specific sectors (e.g. administration) and quantifiable benefits (e.g. time savings and productivity gains), whereas other studies often include different scenarios (e.g. best case and worst case scenario), uncertain or unquantifiable benefits. The results suggest an 0.48 times higher *BC* ratio for assessments with a range of *BC* ratios than for assessments with a definite *BC* ratio. The "true" *BC* ratio may, therefore, be larger than expected or estimated in most studies.

Time has the smallest but yet a significant impact on the *BC* ratio. In contrast to the simple linear fit in Figure 1, the time trend of the multivariate model suggests that the average *BC* ratio increases with time. Time is usually associated with technical progress, economic and social development. Over the past decades the adoption of technical devices (e.g. phones, computers), Internet access per capita as well as the awareness of environmental changes (e.g. climate change) have increased. Interest and accessibility of data, and thus, the number of users has grown. These developments could have lead to increasing benefits or decreasing costs of GI.

Private organizations are often more willing to finance innovative projects, can be more flexible in responding to unique needs, avoid bureaucratic requirements or provide additional assistance. Conversely, public organizations often award larger grants and make funding available to a wider array of organizations. Therefore, the source of funding or the organization which implements the investments are expected to play an important role for the *BC* ratios. Although the results do not show a significant impact between public and private organizations, co-operational investments by public and private organizations, for example, public-private partnerships, have significantly higher *BC* ratios than public investments. Public-private-partnerships enable governments to access new sources of financing, and thus, to increase the scale of investments and to exploit economies of scale. The shared costs and increased returns can lead to higher *BC* ratios.

Finally, there are various types of methodologies to assess the costs and benefits of GI investments. Comparing the *BC* ratio of CBA and ROI against other methodologies suggests that methodologies have no significant impact on the *BC* ratio.

On average, the predicted benefits are three times larger than the cost. Depending on the study and investment characteristics, the predictions can vary from 0.6:1 to 7.2:1. Most assessments, however, ignore unquantifiable benefits which can increase the *BC* ratios significantly. In addition, the regression results explain only some of the variation in the *BC* ratios whereas almost 50% remains unexplained.[6] Explaining unexplained variation and including unquantifiable benefits can, therefore, result in much higher *BC* ratios.

5 Robustness Checks

Due to the small sample size it is difficult to attain a normal distribution of the data. Therefore, it is important to illustrate the robustness of the findings. Firstly, we re-sample the data to obtain a bootstrap sample and re-estimate all models, and secondly, forecast recursively and compare the difference between the predicted and observed *BC* ratios.

Bootstrapping is a method for statistical inference based on the sampling distribution of the data. Re-sampling allows us to evaluate the sensitivity and robustness of the results. We draw 60 subsamples with replacement from the original sample and re-estimate each model. This enables us to obtain estimates with more accurate standard errors and statistical significance. The results for the bootstrapped models are presented in Table 5. Repeating the estimation on the subsamples significantly increases the standard errors of the regional scope, the socio-economic focus, the valuation point, the source of funding and of SDI elements. This reduces the significance of the national scope and the miscellaneous funding below the 10% level and for the socio-economic focus and the valuation point to the 5% level. Notably, the SDI elements in the investment exhibit insignificant impacts on the *BC* ratio. Thus, some of the aforementioned variation across *BC* ratios related to infrastructure elements may be due to other differences, such as unexplained study characteristics or regional factors. These findings are noteworthy in that they suggest that investments into infrastructures and geospatial data have similar returns.

Furthermore, we forecast recursively and compare the predictive power of the model. We construct two data samples: in-sample data for 80% of the observation and out-of-sample data for the remaining 20% of observations. By randomizing the data, we ensure unbiased estimates. The *BC* ratio for the out-of-sample data is predicted using the estimated parameters of the in-sample data. To test the in-sample model accuracy, we assess the prediction error by calculating the Root Mean Square Error (RMSE).[7] The results suggest a moderately low in-sample prediction error (RMSE = 1.0) for the out-of-sample predictions. Furthermore, a paired t-test reveals that the observed and predicted *BC* ratio are not significantly different, but the predicted *BC* ratio of the out-of-sample tends to be insignificantly lower than the observed *BC* ratio in the in-sample.

Table 5 Bootstrapped regression results of the *BC*-Ratio (60 replications)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Variance > 0	0.472***	0.479***	0.379***	0.448***	0.437***	0.433**	0.461***	0.477***	0.469***	0.457***
	(0.105)	(0.0677)	(0.142)	(0.117)	(0.130)	(0.169)	(0.108)	(0.126)	(0.116)	(0.170)
Ex-Post		1.144***	0.835*	1.119***	1.154**	0.971**	1.018*	1.178*	1.070*	1.067*
		(0.464)	(0.495)	(0.379)	(0.495)	(0.470)	(0.542)	(0.608)	(0.648)	(0.611)
Regional			–1.346	–2.119***	–1.945**	–1.981*	–2.315***	–2.550***	–2.746***	–2.772**
			(1.086)	(0.797)	(0.935)	(1.157)	(0.796)	(0.928)	(0.723)	(1.161)
National			–0.235	–1.153	–1.048	–1.027	–0.782	–0.999	–0.964	–0.950
			(0.955)	(0.961)	(0.839)	(0.966)	(0.874)	(0.927)	(0.907)	(1.095)
Eastern Europe				1.355	1.158	1.610	1.360	0.932	1.032	1.051
				(0.996)	(0.858)	(1.377)	(1.102)	(1.189)	(1.242)	(1.282)
North America				1.450**	1.717***	2.113**	2.262**	2.470***	2.203***	2.188**
				(0.634)	(0.601)	(0.856)	(0.913)	(0.806)	(0.789)	(0.881)
Australia & NZ				1.411**	1.444*	1.768*	3.180***	4.202***	3.854***	3.853***
				(0.666)	(0.805)	(0.934)	(1.064)	(1.274)	(1.479)	(1.465)
Socio-economic					–1.465*	–1.594*	–1.816**	–1.959*	–2.057*	–2.022
					(0.764)	(0.965)	(0.743)	(1.008)	(1.162)	(1.352)
Organizational					–0.383	–0.495	–0.528	–0.479	–0.498	–0.444
					(0.560)	(0.735)	(0.580)	(0.652)	(0.633)	(0.698)
SDI & GEOSS						0.889	1.222	1.364	1.557**	1.596
						(0.906)	(0.827)	(1.034)	(0.707)	(1.069)
Time trend							0.112*	0.161***	0.139*	0.137
							(0.0663)	(0.0575)	(0.0805)	(0.0839)
Private funding								0.242	0.608	0.676
								(0.787)	(0.978)	(1.221)
Miscellaneous funding								1.012	1.276**	1.294*
								(0.659)	(0.648)	(0.683)
CBA									0.327	0.294
									(0.699)	(0.758)
ROI									1.085	1.126
									(1.093)	(1.373)
Private organization										0.0122
										(1.081)
Miscellaneous organsiation										0.318
										(1.277)
Constant	2.681***	2.116***	3.056***	2.538***	2.595***	2.304**	0.143	–1.321	–1.192	–1.216
	(0.307)	(0.359)	(0.120)	(0.712)	(0.750)	(0.906)	(1.121)	(1.089)	(1.077)	(2.061)
Observations	74	74	74	74	74	74	74	74	74	74
R-squared	0.238	0.308	0.368	0.421	0.450	0.467	0.499	0.533	0.544	0.545

Note: Huber-White robust standard errors in parentheses, ***significant at the 1% level, **significant at the 5% level, *significant at the 10% level

6 Conclusions

The main objective of this study is to explain the variation in returns on investments in geoscientific information and to provide a tool for a better understanding of the underlying patterns and distribution of benefit-cost (*BC*) ratios in previous research. The analysis is unique in that it is the first to systematically combine results from previous cost benefit assessments to investigate sources of heterogeneity between studies. By conducting a meta-analysis on 82 assessments and controlling for study-specific characteristics and the investment environment, we are able to identify numerous influences on the *BC* ratio.

Due to regional differences alone, the *BC* ratio can be more than four times higher or lower. The reasons for the substantial regional differences need to be investigated in more detail, especially whether environmental, socio-economic or political conditions determine the benefits of GI. This can help identifying the major barriers and obstacles for GI, especially in Europe where the *BC* ratio is amongst the lowest, and increase the benefits of GI.

Moreover, investments in GI with a national or international focus can increase the number of end-users, exploit economies of scale or harness synergies, which increases the *BC* ratio two to three times compared to regional GI. Therefore, large-scale investments need to be increased and data, tools and maps should be provided to a larger number of users. Strategies for more collaboration across countries need to be developed and international agreements for increased cost sharing should be reached.

The added value of SDI investments, however, remains uncertain. Although the analysis suggests a significantly larger *BC* ratio for SDIs, the results are not robust. Most SDI studies are based on ex-ante assumptions and few on the mature experiences available. More assessments for SDIs are required to examine the added value of SDIs in more detail.

Even though the benefits for the environment and organizations clearly outweigh the benefits of socio-economic investments, most assessments ignore indirect and unquantifiable benefits and interlinkages between the disciplines. Benefits for the environment and society are often interrelated and especially difficult to quantify. Therefore, impact assessments and case studies need to give more attention to non-monetary benefits and increase cross-disciplinary research. In addition, investment risk and uncertainty need to be better reflected in benefit-cost assessments, to improve the comparability and understanding of variation in *BC* ratios. Accounting for both indirect benefits and risk would improve the comparability and increase precision of benefit assessments.

On average, the predicted benefits are more than three times larger than the costs, but many aspects still need to be investigated in more detail, especially, the role of unquantifiable benefits. Nevertheless, this study is the first to systematically examine factors that affect the BC ratio and finds that investing in geospatial data and infrastructure for a more efficient usage of data, maps and tools, is highly profitable and a valuable asset to society and the environment. Thus, geospatial data can contribute to a more sustainable future.

Notes

1 The studies under consideration are listed on http://lyra2.felis.uni-freiburg.de/eurogeoss/biblio?page=1.

2 It should be noted that Longhorn and Blakemore (2008) discuss the different definitions and meanings of geo-information and are quite critical of methodologies of the ROI, especially the consideration of unquantifiable, intangible and secondary benefits. For example, the ROI can be increased or decreased due to a consideration of unquantifiable benefits (e.g. loss of habitat), data sampling problems (e.g. accuracy, currency) or technical issues (e.g. data formats, interoperability). Longhorn and Blakemore (2008) emphasize that many different types of information can be labeled as geographic and make it difficult to assign a value to GI in general terms, so they conclude that it is especially difficult to assign a value to geographic information. A meta-analysis allows for a control of the various study characteristics, methodologies and for several benefit areas, and therefore, generalizes the *BC* ratio for a larger number of studies and improves the precision and accuracy of the profitability of GI investments. Furthermore, we include negative observations, whereas Longhorn and Blakemore (2008) did not find any negative benefit-cost ratios for GI.

3 Assessments targeting developing or emerging countries where also relevant GI benefits could be achieved are not available or constituted outlying observations, but could alter the overall results.

4 We apply the Box-Cox regression model by Box and Cox (1964) in order to stabilize variance and to attain a more normal distribution of the data. The Box-Cox regression model is specified as:

$$Y^{(\theta)} = \begin{cases} \dfrac{Y^{\theta}-1}{\theta} & \text{for } |\theta| > 10^{-10} \\ \ln(Y) & \text{otherwise} \end{cases}$$

The corresponding concentrated log-likelihood function for the left-hand-side model is specified as follows: $\ln L_c = \left(-\frac{N}{2}\right)\ln(2\pi) + 1 + \ln(\hat{\sigma}^2) + (\theta - 1)\sum_{i=1}^{N} \ln y_i$. The Box Cox regression yields a $\theta = 0.68$ for the dependent variable, suggesting a square root transformation ($\theta = 0.5$) or no transformation ($\theta = 1$), respectively. However, a square root transformation reduces information value and a definite improvement of the distribution cannot be obtained. Therefore, the model is estimated with a linear *BC* ratio

5 The results were significantly improved omitting eight visually identified outliers as was done for North America in the regional box plots. All outliers are denoted by asterisks in Table 1.

6 From a statistical point of view, an R^2 of 0.53 is satisfactory for the cross-sectional analysis.

7 The Root Mean Square Error is calculated by $\sqrt{\frac{1}{N}\sum_{i=1}^{N} \varepsilon_i^2} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (\hat{\sigma}_i - \sigma_i)}$ where $\hat{\sigma}_i$ is the fitted value of the *BC* ratio and σ_i represents the observed value of the *BC* ratio.

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