Reviewing Geoinformation in the Light of Recent Economic Theory (Keynote GeoValue 2010)

gz5020 svn 3648, Hamburg September 2010 Keynote

Andrew U. Frank, Gusshausstrasse 27-29/E127.1 A-1040 Vienna, Austria
frank@geoinfo.tuwien.ac.at

Abstract

Understanding the value of GIS is understanding the value of the information produced by the GIS; early GIS proponents argued for the economic advantages of geographic information systems using standard methods of management science. Only after advances in economic theory during the 20th century were absorbed by GI scientists, a theory to establish the value of geographic information per se could be approached. In this essay, I trace the development by discussing contributions assignable to six Nobel Laureates in economy. After a brief outline of how value of geographic information can be measured, challenges posed by the contributions of two recent Nobel Laureates to GIS and its use are discussed.

1 Introduction

The father of geoinformation was the desire of administration and politics for better space related information [Larsen et al., 1978] to reduce political conflicts around large projects and to increase efficiency of public administration [Eichhorn, 1978]; the mother was computer technology promising to satisfy this demand [Dutton, 1979]. For accounts of the history of GIS from directly involved witnesses check the GIS history project [1] (and accounts like Foresman [1998], Coppock and Rhind [1991], Chrisman [2006], Frank [1983]). The challenges for GIS today are still related to make good use of technology to serve mankind; two recent economy nobel laureates pose important challenges to GIS in a time of global problems like "Global Warming". I will come back to challenges but first I intend to outline how researchers learned to assess the value of the information produced by a GIS.

[1] http://www.ncgia.buffalo.edu/gishist/

Questions whether GIS were cost effective were posed only when a number of GIS were operational, especially, when large public others computerized their graphical files. At the conferences on Automated Mapping and Facilities Mapping (AM/FM), attended mostly by public utility personnel, the economic justification for GIS were detailed [Conference]. The assessment for GIS in public administration applied standard methods from business economics [Clapp et al., 1989]. Research to determine the value of geoinformation was proposed by the NCGIA [1989] and lead to a specialist meeting focusing on the topic [Onsrud et al., 1989] and produced later a journal article [Calkins and Obermeyer, 1991]. The book by Didier [1990] in French was unfortunately not translated. The relation between quality and economic value Krek and Frank [1999b,a] lead to Krek and Frank [2000] and finally to the thesis by Krek [2002].

Geoinformation, as much other information, is valuable and the success of the GI industry depends in the long run on a proper assessment of the value of its product. The early history of GIScience did not include economic value of the information, probably because economic theory as it was typically taught when the GIScience pioneers were educated did not assign a value information. In general, our society has not assigned value to information and in daily life we expect that information is given freely—imagine you being asked for a contribution if you ask somebody on the street for the way!

This essay traces the key steps in economic theory permitting to develop a method to assess the value of geoinformation. The necessary improvements of classical economic theory are surprisingly recent and I link them to nobel laureates in economy of the past 40 years; I ask the reader to bear with me the generalizations and simplification necessary to make it—hopefully—a good story. "Se non è vero, è ben trovato". I picked from the list of laureates the one I felt made the most relevant contribution to GIScience and present them here; the choices are personal and open to debate. The essay is written for GIScientists, not economists, and necessarily leaves out many interesting points of debate.

I have read over the past years many of the key contributions of nobel laureates in economics and was surprised to find well written books from which I benefitted enormously. I recommend the lecture—at least of the references given here.

2 Classical Economy: Paul Samuelson (laureate 1970)

The classic text "Economics" by Samuelson [1967], from which generations have learned the basic concepts as handed down from Adam Smith [1993], Ricardo [1817; reprint 1996], Marx [1867; translated reprint 1992] and transformed to the now dominant "neoclassical economy" with the as-

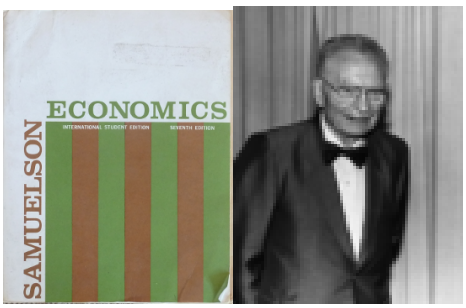

Fig. 1: Samuelson Economics

sumptions:

1. People have rational preferences among outcomes that can be identified and associated with a value.
2. Individuals maximize utility and firms maximize profits.
3. People act independently on the basis of full and relevant information.

[2]

Markets work optimally, if

- nobody dominates the market (perfect competition),
- information about transactions are known by everybody,
- people decide rationally (homo economics).

The above is the case only for idealizations as farmer markets, where many farmers offer corn or potatoes to many small buyers. Perfect markets lead to an equilibrium, at which resource allocation is optimal and production maximal—Adam Smith's invisible hand.

In this view of (micro-) economics, transaction cost are zero and information is a public good, available freely to everybody and has therefore no value. This theory leaves no place for trade, as Marx criticized, and the communist state economics tried to function without—for a while. The real world operates observably different, as the rich silk trading homes and banks in Zurich demonstrated. If empirical evidences and theory contradict, one is ill advised to declare reality wrong and go with the theory; two points were attacked: rationality of decisions by Simon and zero transaction cost by Coase and later by Williamson, student of both.

3 Bounded Rationality: Herbert Simon (laureate 1978)

The rational decision making of the participants in the market is a cornerstone of classical economic theory, but we all know from introspection and observation of others, that humans do not always make rational decisions. Rationality of decision making is limited by the available information and

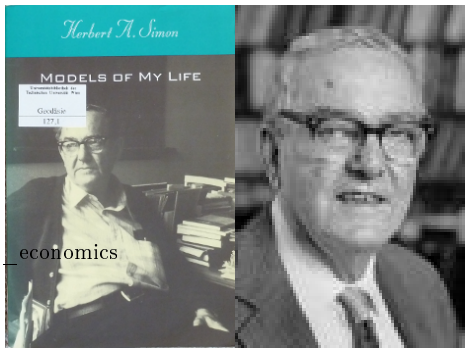

Fig. 2: Simon Models of my life

[2] http://en.wikipedia.org/wiki/Neoclassical_economics

how much of it is acquired and used in the decision process.

Numerous empirical studies have since shown different factors influencing the rationality of human decisions:

- accounting for uncertainty in the data,
- risk in the execution of a plan,
- amount of information acquired,
- idiosyncrasy of decision making by Kahneman and Tversky [1979] (Kahneman was 2002 nobel laureate) [Gigerenzer et al., 1999].

In this theory acquisition of information bears a cost—empirically obvious, but missing in theory. Bounded rationality was an important step to increase reality to economic theory.

aside: Herb Simon is the only Nobel Laureate, who also received the Turing award—the nobel price of computer science; note that his academic background was neither economy nor computer science!

4 Transaction Cost Economy: Oliver Eaton Williamson (laureate 2009)

Williamson [1985]Williamson [2005]

If information is not a free public good and acquisition of information bears a cost, then transactions are not free any more, but transactions are associated with a cost: if I buy and sell goods at the same price then I do not break ever, but lose each time my effort in making the deal.

The cost of transactions can be split in

- discovery cost: the cost of getting the information about the potential deals available and selecting the best one.
- measurement cost: the cost to "measure" the good I have acquired and ascertain that I got what I paid for.

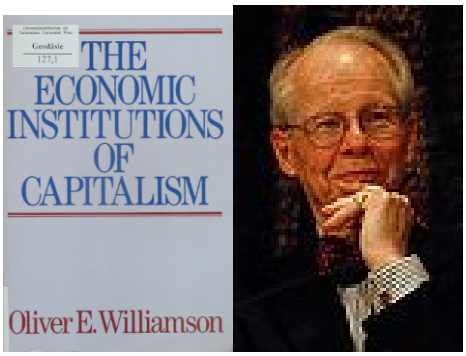

Fig. 3: Williamson Capitalism

- enforcement cost: the cost of enforcing a contract if one of the parties does not fulfill it.

GIS provide information possibly in all phases of a transaction: for example, a cadastre records the location, size, and ownership of a land parcel; it can be used to find a suitable parcel, to determine its size authoritatively and registration procedures reduced enforcement cost and related risks.

5 A Theory of the Firm: Ronald Harry Coase (laureate 1991)

Coase delighted in attacking differences between elegant theory and empirical evidence, for example in his very readable description of a counterexample to the regular assumptions in economic theory that lighthouses must be necessarily a public good [Coase, 1974]. In his influential essay "The Nature of the Firm" [1937] he investigates the contradiction between the observation that Companies in various forms dominate our economy but in a world of perfect markets they would not be necessary.

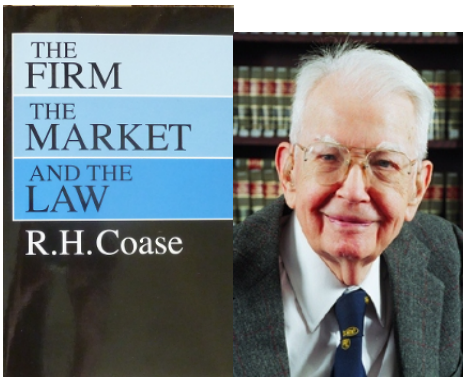

Fig. 4: Coase Firm Market Law

Adding transaction cost to the theory, firms become justified: A firm aggregates multiple production steps and avoids the cost of internal transactions. As a consequence, the inputs a firm acquires (materials, labor, etc.) and the products it sells are structured to reduce transaction cost and transactions with potentially high cost, are integrated into the firm. Typically, transactions where quality is hard to measure, where substantive amounts of firm specific knowledge is required etc. are internalized. A firm has a single goal and a single production of benefit, and is thus—ideally—a single realm of trust (reality is often different; here management "science" and consultants come in!).

For GI business the theory of firms by Coase and furthered by Williamson gives instruction where and how businesses should organize: wherever the quality of data is difficult to control, data acquisition and updating should be internal to the organization!

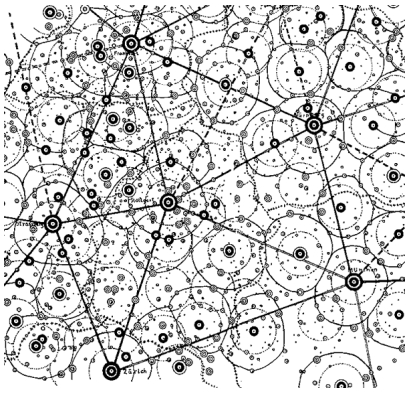

Fig. 6: The structure of central places in southern Germany (top node is Frankfurt, bottom is Zurich, left is Munich)

6 New Economic Geography: Paul Krugman (laureate 2008)

Classical economic theory dealt with a single market—ignoring the reality of space. The influence of the spatial distribution had already been studied by Von Thünen [1826] and 1933 by Walter Christaller in "Theorie der Zentralen Orte" [1966]. Von Thünen pointed out that transportation cost—another form of transaction cost—are roughly proportional to distance and therefore optimal selection of crops would be a function of yield and transport cost, leading in an isotropic space to rings around a market. Empirical evidence of distribution of agriculture around farm villages confirms the theory.

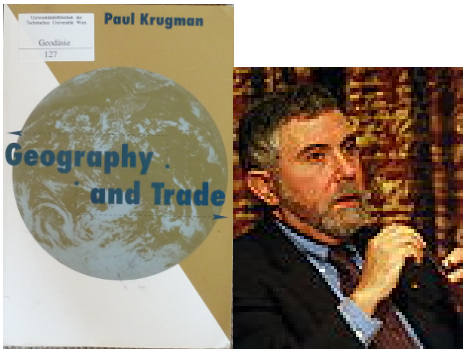

Fig. 5: Krugman Geography and Trade

Christaller found a regular pattern of towns, from small to large in the relatively isotropic area of southern Germany (Figure 6).

He explained the aggregation of services in a hierarchical order of town by frequency such services are required and willingness to move to find them. Bread is bought more often than going to the dentist; therefore bakeries should be closer, more frequent, than dentists.

Krugman has extended economic (formal) theories with spatial considerations [Fujita et al., 2000, Krugman, 1991]. The models are complex and the spatial aspects are very abstract, often investigating a linear world in which multiple city centers occur. Important remains the fact that Krugman has intro-

duced Geography (again) in economy; his theories are important when studying physical and urban planning, and can be used in cellular automata simulation with GIS (for a recent review Torrens [2009]; the comparison of Krugman's studies and the review of current practice in GIS spatial simulation by Torrens show much room for future integration).

7 Institution Economics: Douglass Cecil North (laureate 1993)

Douglass North is a historian, investigating not markets (microeconomics) but societies (macro economics). He studied the major methods in societies to make decisions and arrange for resources allocation. He found over long time spans the construction of increasingly elaborate systems of rules to organize society, called institutions [North, 2005]; very similar to what John Searle, from the point of view of a philosopher calls "social reality" [Smith and Searle, 2001]. For example "marriage" is a social construction, an institution consisting of a complex set of rules for inheritance, divorce organizing "raw" cohabitation of couples.

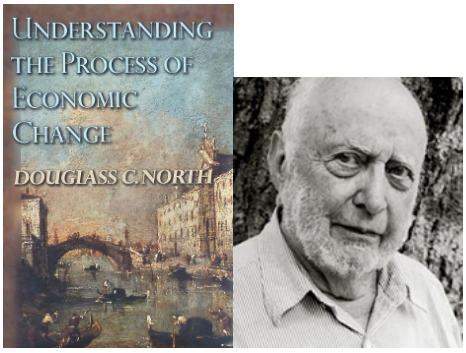

Fig. 7: North Economic Change

Cadastre, registry of deeds and registry of title to land are the main institutions served by GIS. The theory of institutions [Alston et al., 1996] has helped to understand cadastre [Navratil and Frank, 2004], compare cadastral systems [Stubkjaer, 2001], and to assess the value of their services.

8 A Theory of Values of Spatial Information

With this background, the value of (spatial) information, here value is considered as utility, can be assessed. Assuming (bounded) rational behavior of agents with subjective preferences, agents will acquire a good if its consumption gives more utility than some other goods they could acquire and consume. If geographic information is offered on a market it competes with other information and other goods; it has economic value, when it is used in a decision and leads to an improvement of the decision. To assess the economic value of information, one has to consider a decision process:

Assume we have to make a decision between two actions (alternatives a_1, a_2, or a_3). Carrying out a_1 results in a situation s_1, carrying out a_2 or a_3 leads to s_2, or s_3. The value of situation s_1 for use is estimated by the decision maker

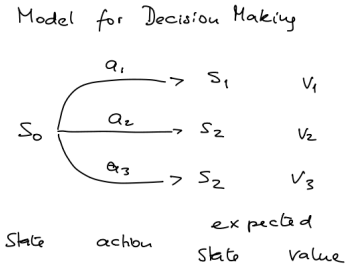

Fig. 8: Diagram showing decision situations between different actions a_1, a_2, and a_3 leading from a situation s_0 to states s_1, s_2, or s_3, which are valued at v_1, v_2, or v_3

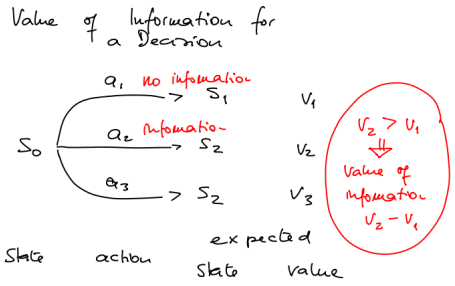

Fig. 9:

to v_1 and of s_2 or s_3 is v_2 or v_3, with $v_2 > v_2$ and $v_2 > v_3$. A rational decision maker will select a_2 because it is his "best action".

If the difference between the actions a_1 and a_2 is in additional information acquired for a_2 then, the value of the information going into a_2 and not in a_1 corresponds to the difference $v_2 - v_1$.

For example: I need to go by train to Graz; I have two alternative actions:

a_1: I go to the station without consulting the timetable,

a_2: consult the timetable and go to the station with appropriate anticipation to the departure time.

The expected outcome of a_1 is to wait for the train whatever it takes, for a_2 is staying at home and use my time and a short wait at the station. The subjective evaluation is for a_1 based on my knowledge that there is a train every hour; on average I will wait 30 minutes. For a_2, after consulting the timetable, I can reduce wait time to, for example, 10 minutes I need to allow for delays of one or another kind. The difference between a_1 and a_2 is equivalent to the value of 20 minutes of my time, which is the value of the information I obtain from consulting the timetable (deduce the time it takes to read the timetable).

The value of information is the contribution it makes to improve a decision; this is analogous to the value of materials in production, where the value of the material for the production process is the contribution it makes to the product. To compensate for uncertainties and risk generally involved in decisions, the amounts are determined as expected values based on past experience—for example in order to take the U-Bahn in Vienna during day consulting a timetable is not warranted, because experience tells that there is only a "short wait".

In these cases, the decisions were between making a decision without information compared with the decision to acquire information and then produce a better plan for an action; in the example the "plan" is: when to leave home to go to the station. In other cases geographic information can help us to select among alternatives then one which reduces the use of a resource to achieve the same goal. For example, car navigation systems help us to get to a destination often on a shorter route we would travel without the information from the system; the value is the reduction in time and gas.

Values assigned to information are, obviously, specific to the situation and includes subjective elements—in this value of information is not different from value for other goods: I prefer wine over beer and therefore value wine higher than beer—many of my colleagues prefer beer and there are options for trading benefitting all.

9 Challenges: GIS Were Built to Improve the Human Condition: Amantya Sen (laureate 1998)

Many of the GIS researchers come to the topic with a desire to build system to help humanity to improve the situation of the world: protection of resources, avoiding climate changes reducing effects of earthquakes, flooding, etc. and generally increase happiness [Wilkinson and Pickett, 2009]. Amantya Sen is one of the most prominent economist arguing for human freedom and happiness. He believes that freedom to make one's own decision is crucial for a dignified human life, and freedom includes and is based in economic freedom. He reports from countries in development, primarily his origin India, and contradicts with empirical evidences misconceptions about the third world in the first world. An example that impressed me: From observation of temporal occurrence of catastrophic droughts, destroying crops, and hunger in the population, he concludes that not shortage of staples causes hunger, but the absence of gainful employment in tending the crops of the landowners leads to lack of money to

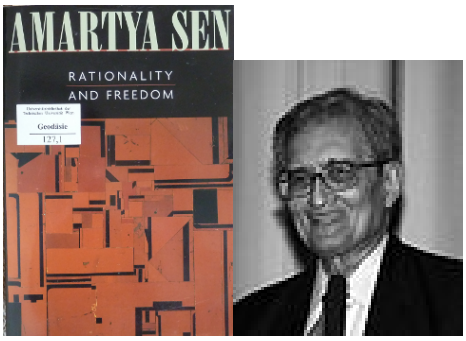

Fig. 10: Sen Rationality

buy. Shipping corn from Europe or USA by well meaning humanitarian aid organizations is not effective—or, how others have argued, even by Myrdal et al. [1968], destroys agricultural markets for long time after the drought catastrophe.

Corruption, i.e., a lack of effective legal institutions, may be a major cause of hindering development. The third world often lacks secure land tenure systems, protecting the ownership of land by smallholders. Many have argued for cadastral systems in developping countries [De Soto and Llosa, 1989][Williamson, 1997]. De Soto has correctly indicated that exporting "institutions" as they exist in Europe or the USA is not necessarily leading to functioning systems [De Soto, 2003], societies must go through development processes for institutions. We seem to have forgotten how we arrived at today's very complex rules guiding our instructions [Frank, 2007]. Analyzing the complex institutions of today's developed nations and identify the core concepts and functions may be a path to simpler solutions, working in environments with a less refined legal tradition [Navratil and Frank, 2007]. This applies to cadastre, and generally to use of GIS in administration and planning, as the last my nobel laureate argues:

10 Overcoming the Tragedy of the Commons: Elinor Ostrom (laureate 2009)

Improving the management of natural resources are important applications of GIS. Natural resources often from a "Common Pool Resource" available for exploitation by a group; examples are the marine fish populations, fished by fisher boats from everywhere, but also groundwater or oil reservoirs, which can be exploited by wells owned by different organizations. Common Pool Resources are often overexploited and regulations are required; fish populations are currently a focus of the European commission.

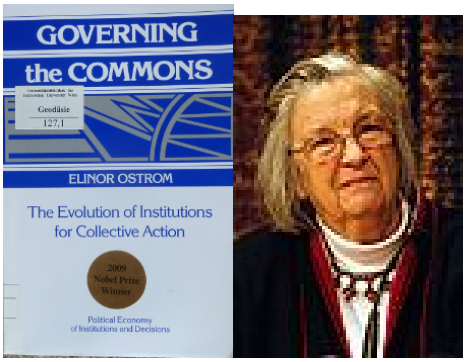

Fig. 11: Ostrom Governing

The situation of a Common Pool Resource is a standard problem treated in the economic literature discussed as the "Tragedy of the commons", taking as an example grazing ground held in common by farmers in a village. Every user in his best self interest will acquire as much as possible from the CPR, even though the joint action by all will destroy the CPR. In the classic example, every farmer will bring as many cows to the commons because each cow is an additional benefit to him, till the land is bare and the resource lost for all (Hardin [1968] referencing classic work by Lloyd in the early 19th century [1833]). This theory suggests two solutions, which are embraced by different political parties:

1. construct private ownership rights in the CPR assuming that each owner then manages in his own interest, his part optimally, or

2. construct a governmental administration for the CPR.

Empirical evidence, however, indicates

(a) there are CPRs that have been properly managed without (1) or (2)

(b) neither privatization (1) nor administration (2) leads often to long term optimal use of the CPR.

Examples are alpine meadows that are managed in common by alpine villages, forests and fish populations managed for long term survival by traditional societies. Eleonore Ostrom received as first woman the Nobel Prize for economy for careful empirical analysis and theoretical explanation how CPRs are effectively managed. Building of institution through trial and error, establishment of trust among the participants (building a kind of "firm"), and rules that minimize transaction cost—especially measurement and enforcement cost—seem to be crucial in all CPR that are effectively managed over long time periods.

Modern "scientific" methods imposed from administration are often correct from the position of natural science (e.g., fish biology) but are economically inviable because the transaction, especially measurement and enforcement cost, are too high. Nice rules are established, but personal for measurement and political will for enforcement is not forthcoming and the tragedy of the commons is played to the dire end.

What can GIS contribute to the effective management of CPR:

- Identify the regional limits of independent CPR and the population concerned.

- Forms of volunteered Geographic Information VGI [Goodchild, 2007] and GIS as a distinction and visualization tool may help reduce transaction cost and increase trust.

The theory of CPR applies not only to the tangible resources like fish, wood, or grass that is harvested but also to the use of the environment to dump pollutants into it: plastic and oil into the world's oceans, CO_2 into the atmosphere as already Hardin has pointed out (he also included noise pollution and advertisement in his list of what could be called negative CPR). GIS can also help to avoid unviable sets of rules when analyzing the level of quality of data required and spelling out the associated cost for its collection [Frank, 2008].

11 Coda

Economic theory has evolved in the past 50 years from a traditional social science to a much more formal and empirical science observing social phenomena. This transformation has been often advanced by critical researchers questioning widely accepted theory and comparing it with contradicting evidence.

The transformation from classical and neo-classical economy to an economic theory including transaction cost results in methods to quantitatively assess the value of information in decision situations; it is of eminent importance to structure the emerging business in Geographic Information.

The transformation in economic theory has also changed our theoretical book to deal with the global challenges to which GI can make important contributions.

References

Lee J. Alston, Thrainn Eggertsson, and Cecil North Douglass, editors. *Empirical Studies in Institutional Change*. New York: Cambridge University Press, 1996.

H.W. Calkins and N.J. Obermeyer. Taxonomy for surveying the use and value of geographical information! *International Journal of Geographical Information Science*, 5(3):341–351, 1991. ISSN 1365-8816.

N.R. Chrisman. *Charting the Unknown: How computer mapping at Harvard became GIS*. Esri Press, 2006. ISBN 1589481186.

Walter Christaller. *Central Places in Southern Germany*. Prentice Hall, 1966.

J.L. Clapp, J.D. McLaughlin, J.G. Sullivan, and A.P. Vonderohe. Toward a method for the evaluation of multipurpose land information systems. *Journal of the Urban and Regional Information Systems Association*, 1(1):39–45, 1989.

Ronald H. Coase. The lighthouse in economics. *Journal of Law and Economics*, 17(2):357–376, 1974. ISSN 0022-2186.

Ronald.H. Coase. The nature of the firm. *Economica*, 4(16):386–405, 1937. ISSN 1468-0335.

AM/FM International. Summer Conference. *Proceedings: AM/FM Summer Conference, Snowmass Conference Center, Snowmass, Colorado, July 18-21, 1988*. AM/FM International.

J.T. Coppock and D.W. Rhind. *The history of GIS*, volume 1, pages 21–43. 1991.

H. De Soto. *The mystery of capital: Why capitalism triumphs in the West and fails everywhere else*. Basic Civitas Books, 2003. ISBN 0465016154.

H. De Soto and M.V. Llosa. *The other path*. Harper & Row New York, 1989. ISBN 0060160209.

Michel Didier. *Utilité et Valeur de l'Information Geographique*. Edition Economica, 1990.

Geoffrey Dutton, editor. *First International Study Symposium on Topological Data Structures for Geographic Information Systems (1977)*. Harvard Papers on Geographic Information Systems. Harvard University, also published by addison-wesley, reading ma edition, 1979.

Gerhard Eichhorn. Landinformationssysteme. Symposium der Fédération Internationale des Géomètres (FIG). THD Schriftenreihe Wissenschaft und Technik 11, 1978.

T.W. Foresman. *The history of geographic information systems: perspectives from the pioneers*. Prentice Hall, 1998. ISBN 0138621454.

A. U. Frank. *Datenstrukturen für Landinformationssysteme: Semantische, topologische und räumliche Beziehungen in Daten der Geo-Wissenschaften*. Institut für Geodäsie und Photogrammetrie an der Eidg. Technischen Hochschule Zürich, 1983.

A. U. Frank. *The Mystery of Capital and the New Philosophy of Scocial Reality*, chapter A Case for Simple Laws, page 288. 2007.

A. U. Frank. Analysis of dependence of decision quality on data quality. *Journal of Geographical Systems*, 10(1):71–88, 2008.

M. Fujita, P.R. Krugman, and A. Venables. *The spatial economy*. Mit press, 2000. ISBN 0262062046.

Gerd Gigerenzer, Peter M. Todd, and al. et. *Simple Heuristics That Make Us Smart*. Oxford University Press, paperback edition, 1999. ISBN 0-19-514381-7.

M.F. Goodchild. Citizens as sensors: the world of volunteered geography. *GeoJournal*, 69(4):211–221, 2007. ISSN 0343-2521.

G. Hardin. The tragedy of the commons. The population problem has no technical solution; it requires a fundamental extension in morality. *Science (New York, NY)*, 162(859):1243, 1968.

Daniel Kahneman and Amos Tversky. Prospect theory: An analysis of decision under risk. *Econometrica*, 47:263–291, 1979.

Alenka Krek. *An Agent-Based Model for Quantifying the Economic Value of Geographic Information*. PhD thesis, 2002.

Alenka Krek and Andrew U. Frank. Pricing geographic data. *GIM International*, 13(9):31–33, 1999a.

Alenka Krek and Andrew U. Frank. The economic value of geo information. *Geo-Informations-Systeme - Journal for Spatial Information and Decision Making*, 13(3):10–12, 2000.

Alenka Krek and A.U. Frank. Optimization of quality of geoinformation products. In P.A. Whigham, editor, *Proceedings of 11th Annual Colloquium of the Spatial Information Research Centre, SIRC'99,*, pages 151–159, Dunedin, New Zealand (13-15 December, 1999), 1999b. Dept. of Information Science, University of Otago.

P. Krugman. Increasing returns and economic geography. *Journal of political economy*, 99(3):483–499, 1991. ISSN 0022-3808.

B. Larsen, J.L. Clapp, AM Miller, BJ Niemann Jr, and AL Ziegler. Land Records: The Cost to the Citizen to Maintain the Present Land Information Base. *A Case Study of Wisconsin. Madison: Wisconsin Department of Administration, Office of Program and Management Analysis*, 1978.

W.F. Lloyd. *Two lectures on the checks to population*. JH Parker, 1833.

Karl Marx. *Capital: Volume 1: A Critique of Political Economy*, volume 1. Pengiun Classics, 1867; translated reprint 1992. ISBN 0140445684.

G. Myrdal, S.S. King, and T.C. Fund. *Asian drama: An inquiry into the poverty of nations*, volume 3. Pantheon New York, 1968.

Gerhard Navratil and Andrew U. Frank. Processes in a cadastre. *International Journal on Computers, Environment and Urban Systems*, 28(5):471–486, 2004. URL `ftp://ftp.geoinfo.tuwien.ac.at/navratil/navratilCEUS.pdf`.

Gerhard Navratil and Andrew U. Frank. Expropriation in a simple cadastre. In Kauko Viitanen, editor, *Seminar of Compulsory Purchase and Compensation*. Helsinki University of Technology, 2007.

NCGIA. The research plan of the national center for geographic information and analysis. *International Journal of Geographical Information Systems*, 3 (2):117–136, 1989.

Douglass C. North. *Understanding the Process of Economic Change*. Princeton University Press, 2005.

Harlan J. Onsrud, HW Calkins, and NJ Obermeyer. Use and value of geographic information initiative for specialist meeting: report and proceedings. Technical report, NCGIA Technical Paper 89-7, NCGIA, 1989.

David Ricardo. *Principles of Political Economy and Taxation*. Prometheus Books, 1817; reprint 1996. ISBN 1573921092.

Paul A. Samuelson. *Economics: An Introductory Analysis*. McGraw-Hill, 1967.

Adam Smith. *Der Wohlstand der Nationen*. Deutscher Taschenbuch Verlag Klassik, 6 edition, 1993. ISBN 3-406-05393-9.

Barry Smith and John Searle. The construction of social reality: An exchange. *American Journal of Economics and Sociology*, 60, 2001.

Erik Stubkjaer. *Life and Motion of Socio-Economic Units*, chapter Spatial-socio-economic units and societal needs - Danish experiences in a theoretical context. Taylor & Francis, 2001.

Paul M. Torrens. *International Encyclopedia of Human Geography*, chapter Cellular automata, pages 1–4. Elsevier, 2009.

Johannes H. Von Thünen. *Der isolierte Staat in Beziehung auf Nationalökonomie und Landwirtschaft*. Stuttugart: Gustav Fisher. English Edition: Isolated state, 1826.

Richard Wilkinson and Kate Pickett. *The Spirit Level: Why More Equal Societies Almost Always Do Better*. Allen Lane, London, December 2009. ISBN 1608190366.

I. Williamson. The justification of cadastral systems in developing countries. *Geomatica*, 51(1):21–36, 1997. ISSN 1195-1036.

Oliver E. Williamson. The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting. *Markets, Relational Contracting, New York*, 1985.

Oliver E. Williamson. Transaction cost economics and business administration. *Scandinavian Journal of Management*, 21:19–40, 2005.