Decision-making when complexity prevails

Aviel Verbruggen
University of Antwerp
www.avielverbruggen.be

March 2011

Abstract

Decision-making encompasses three main components that require comprehensive, complete and consistent study: events, alternatives, and outcomes. Outcomes need particular detailing in societal decisions that mostly create winners and losers. The real complexity of decision-making follows from three context variables: time, doubt, and irreversibility. Time ranges from years, over decades to centuries. Doubt shifts from risk, over uncertainty to ignorance. Irreversibility grows from flexibility, over rigidity to preclusion. Irreversibility is measured by gauging three attributes of a decision's impacts: their duration, the costs to reverse the impacts, and the substitutability of valuable subjects, objects or systems affected by the impacts. They provide a framework to measure irreversibility, compatible to the use of the irreversibility concept in the life sciences (thermodynamics). There the relative proportions of system/ environment/ universe, and the quantity and quality of the flows across the three compartments fix the degree of irreversibility and its relative character. Domes of complexity are identifiable in the three-dimensional decision space. Cost-benefit analysis, being the major societal decision support tool, falters when applied on really complex decision problems.

Keywords: decision-making, cost-benefit analysis, irreversibility.

Introduction

This article is the result of a lecture at the University of Ghent on March 2, 2011, on demand of a students' grassroots initiative, calling attention for the irreversible damage men is inflicting on life in the Oceans. Because my research these days is dealing with clarifying the concept of irreversibility I accepted to contribute to the initiative. First I only selected and edited a sequence of slides. But in adding later some notes to the slides, a more textual edition of the lecture became available. This edition is offered here. The figures in this article are some of the pictorial slides of the lecture. The language may not be fully polished.

This article (lecture) is not offering you facts or stories about developments in our modern times that are causing devastating impacts on crucial life support systems, like the oceans are one of them. Every person is exposed daily to massive flows of data, pictures, messages, … spawned by a variety of media. You actually reduce your knowledge by consuming news because the media cannot filter out the vast majority of facts that turn out to be irrelevant.

I invite you for the coming hour to walk together on a path of conceptual discovery, exploring what the components of (societal) decision-making are and in what complex context decision-making is evolving. An important dimension of the complex context is the eventuality of irreversibility. The treatment of irreversibility in science and in politics is rather schizophrenic: on the one hand it is worshipped as highly important and relevant, on the other hand little clarity and consensus about its meaning is established and it is often (mostly) sidelined in societal decision-making. After visiting the concepts, we consider their relevance for societal decision-making, in particular for cost-benefit analysis as the dominant approach in industrialized societies.

Decision-making

Various disciplines foster a vision about the crucial factor distinguishing men from other living species. Energy specialists have argued that the mastering of fire by men has been the definite split in the developments of mankind and of other mammals (Simmons 1989). Philosophers focus on the brains and mind of men, thinking capacity and similar attributes. One property that made men the dominant species on earth is its capacity to plan, exploring the future and making predictions for taking considered decisions. That capacity has developed over time; it is not perfect and never will be. Since the 1960s scientific decision-making gets attention to enhance the human planning capacity and to make it more consistent and robust. Cost-benefit analysis started earlier but became widespread since the 1950/60s when large-scale infrastructure projects were decided in the USA and Europe.

A decision is "an irrevocable allocation of resources" (Matheson and Howard 1968). Decisions can only be made for the future, and by definition the future is badly known and uncertain. For day-to-day, simple, repetitive and transient actions suffices our intuitive decision processor. But for long-term, complex, unique actions with persistent effects and impacts only the best scientifically based methods are warranted. Related to the scope and complexity of decisions is often the kind of decision-maker. Decisions are taken by individuals, households, groups (from small to extended, e.g., institutes, companies, NGOs, etc.), and by politicians as representatives of communities (from local to global). Here we do not deal with "kitchen & garden" issues but with issues that stretch into the far future and are highly uncertain (our doubt is immense), that are complex and unique, and that matter to entire societies and where politics should play a prominent role. The use of and care for the global commons like the oceans or the atmosphere belong to the latter class.

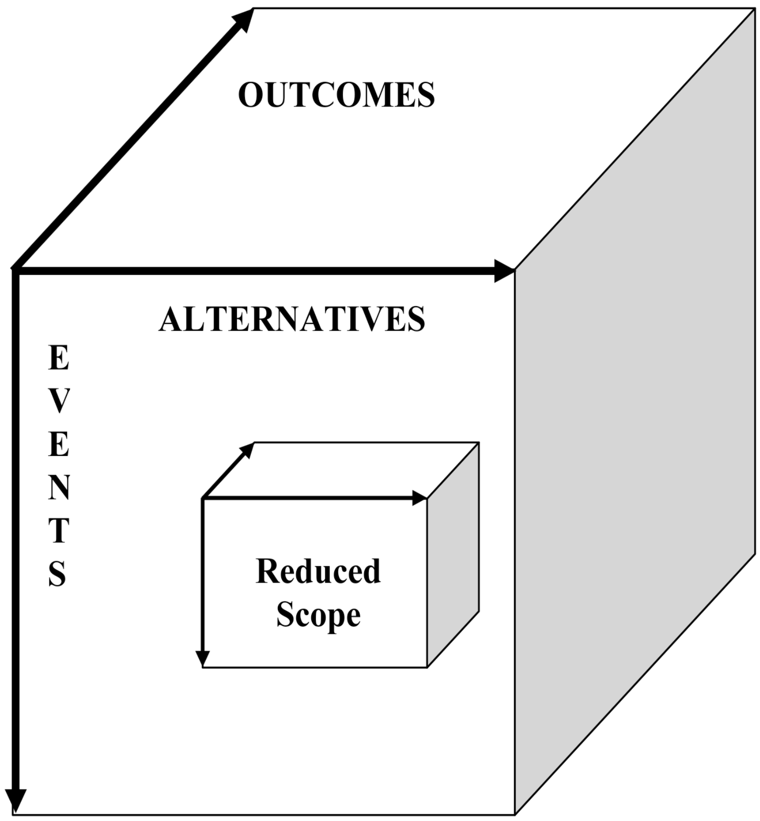
Decision components

Figure 1 shows a box made up by the three structural components of a decision. When a non-trivial decision has to be taken, it always pays off to sit down, take a bloc note and pen (or today: the laptop) for obtaining lists of events, alternatives, and outcomes.

Events are what may happen in the outside world that we cannot influence – they are beyond our power – but of relevance to our decision. When they materialize events affect the field of action and the outcomes in the future.

Alternatives (also called strategies, options, choices, etc…) are the components that we can decide ourselves. Decision analysis offers methods to help you find the best (optimal) strategy by processing in a systematic way a huge quantity of information, preferences, uncertainties, etc.

Figure 1: Three structural components of a decision



Outcomes (also called effects, impacts, consequences, results, etc…) are what matters. We interfere deliberately with the spontaneous course of events to avoid or minimize negative outcomes and to obtain and maximize positive outcomes. Especially in societal decision-making a good catalogue of outcomes is of high importance, because every significant societal decision brings winners and losers. Losers are generally the poorer people, people without power, without influential voice, and last but not least: unborn people that have no voice by definition.

The matrix of figure 1 highlights how the three components make up a room that decision-makers have to design and fill, repetitively when the time-sequential deployment of the future is modeled. Construction of the matrices should be done comprehensively (broad, encompassing), completely (the maze of events, alternatives, and outcomes must be fine enough), and consistently (recognize interdependencies, mutually exclusive or contradictory options, etc.). If not, the danger of analyzing decisions from a too narrow scope lurks (figure 1 represents this as a reduced box inside the wider one). Not only the size of the boxes (comprehensiveness), also the detailed lattice in covering the three dimensions (completeness) is important.

Decision context

Where the decision components are the constituent parts of a decision, the decision context is the environment wherein the decision is constructed. Both components and context may grow complex up to unwieldy, but it is context that people, politicians, economists, scientists, … understand the least. Context indeed may range to heights and depths that challenge the human mind, nerves and soul. Three main factors constitute the decision-making context: time, doubt, and irreversibility.

Time

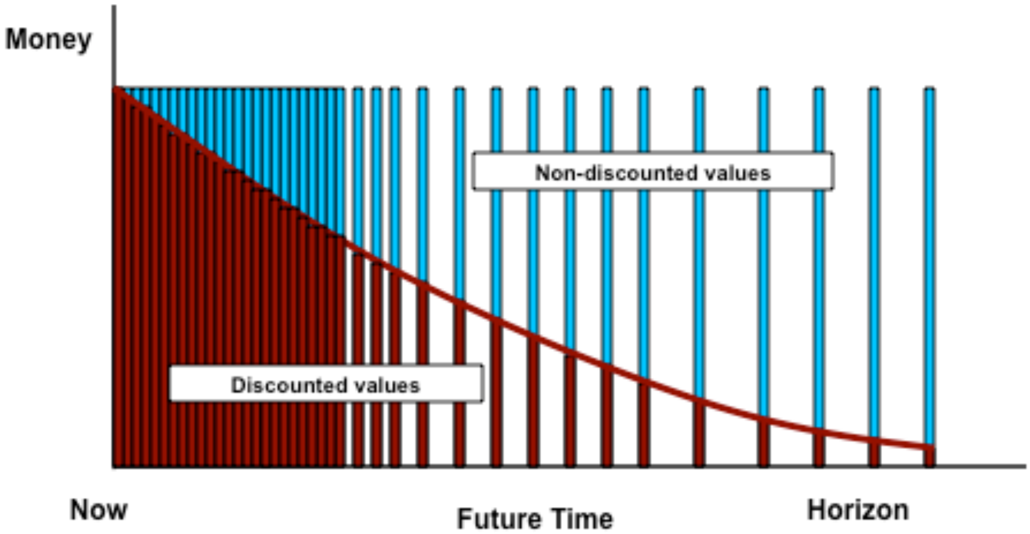
Decisions are made for the future, so future time is a major contextual factor. In principle, for complex, unique, and persistent societal decisions one should look until the end of times, up to perpetuity. This is beyond human capabilities and skills, and therefore mostly a finite time horizon is adopted, what is problematic when deciding on very long lasting or persistent issues (such as the nuclear fuel cycle, loss of biodiversity, desertification of areas, pollution of oceans).

In addition, natural myopia of people is reinforced by the technique of discounting. Economists observe that people prefer to obtain, own, and enjoy, … valuable things like a house, a car, a holiday rather earlier than later. This actual and widely observed attitude is called "time preference", and it explains why money is borrowed from lenders at a positive rate. Discounting the future is based on the rule that future values are less worth than present values, and the further they occur in the future the less worth they are in our accounts today. This is shown in figure 2: we have taken the simple case of a constant yearly value for many years in the future (the blue bars). The standard discounting case is based on a constant discount rate that is applied year after year (like an interest rate), leading to an exponential decay of future values (brown line). Discounting reduces the weight of future values significantly when the time horizon exceeds a few decades (as shown by the brown bars in figure 2).

In addition to being appropriate in expressing daily economic behavior of people, discounting helped in addressing the unsolvable problem of the infinite horizon. However, the problem was not solved but dissolved in a way magicians are juggling: the future is vaporized by a mathematical trick. So far, so good: the trick seemed to work well as long as the future was not backfiring on the present.

Once more enlightened economists started to realize that they had to care for the future beyond a few decades (say 4 decades or 40 years = the active working life of a person), they found out that discounting at constant rates was part of the problem. But even a gathering of a handful Nobel price winners could not bring rescue: economics does not own the theory or methodologies to address the long-term future (Portney and Weyant 1999).

Figure 2: Decision context: Time with finite horizon and discounting



Doubt

The future, in particular the long-term future, is badly known and therefore we live in doubt of what it will bring. Three levels or "depths" of doubt are distinguished: risk, uncertainty, and ignorance (Stirling 1999).

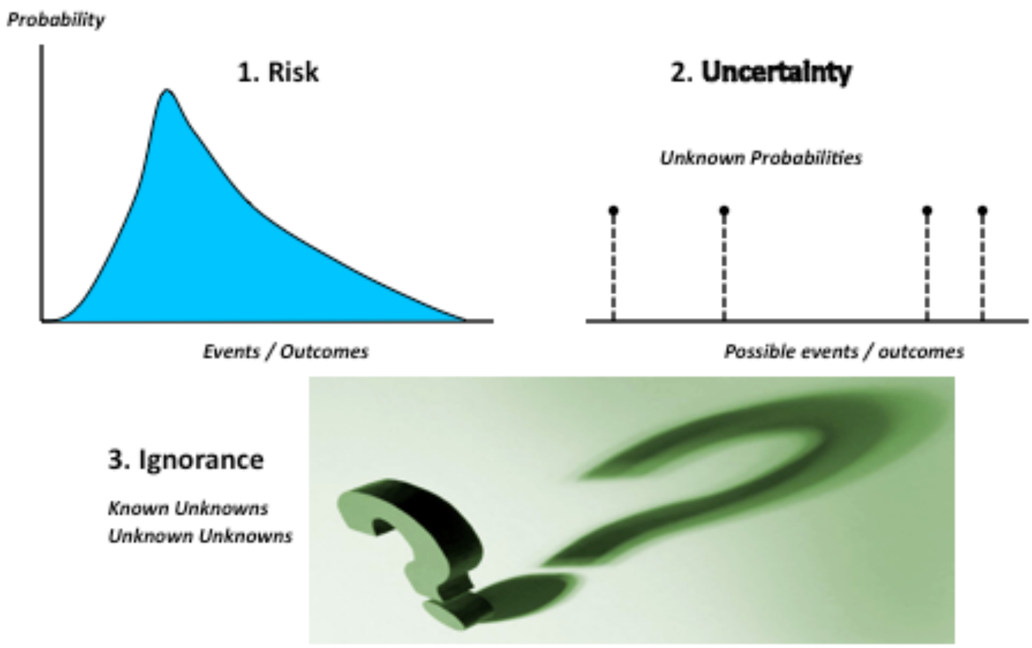
Risk is shallow doubt, rather easy to deal with. In the case of risk one holds a quite good overview of the events/ outcomes that may occur. Also is available the experimental or scientific basis to assess the probabilities of the occurrences. Therefore good knowledge of the relevant, appropriate probability density functions can be obtained.

Uncertainty reflects more doubt: one can obtain an overview of possible events/ outcomes, mostly fuzzier and less complete than in the case of risk. About the likelihood of the various events to happen, very little or nothing is known, for example because some predicted possible future event has never happened before. There is no empirical or scientific basis available to assess the probabilities and one is thrown back on subjective assessments, Delphi panels and similar ways to elicit probabilities.

Ignorance is the abyss of doubt: one has no view on the eventual events/ outcomes that may occur, but one may presume that somewhere out there in the future "black holes" may exist. Some are named "known unknowns" (for example the reversal of the oceanic gulfstream circulations); others are "unknown unknowns" (an example for the future one cannot imagine, but with hindsight: the existence of nuclear power as $E = mc^2$ may function as example of unknown unknowns for the inventors of thermodynamics in the 18th and 19th centuries).

In both cases and in particular in the latter, we have no firm ground to assess the likelihood of such occurrences to happen.
Ignorance is no longer ignored and is receiving more attention because of predicted threats for future sustainability triggered by men's interventions in natural and social systems. For example the Black Swan Theory receives quite some media attention. Black Swan is a metaphor that encapsulates the concept that the event is a surprise (to the observer) and has a major impact. After the fact, the event is rationalized by hindsight. The theory was developed to explain: 1) The disproportionate role of high-impact, hard to predict, and rare events that are beyond the realm of normal expectations in history, science, finance and technology; 2) The non-computability of the probability of the rare events using scientific methods (owing to the very nature of small probabilities); 3) The psychological biases that make people individually and collectively blind to uncertainty and unaware of the massive role of the rare event in historical affairs (Taleb, 2010).

Figure 3: Decision context: Doubt in three depths from shallow risk, over uncertainty to the abyss of ignorance.



The three depths of doubt – risk, uncertainty, and ignorance – are in practice often not clearly demarcated (figure 3 offers a pictorial view of the three). The methodology of decision analysis is ready to process risk information, can address the challenges of uncertainty (to some degree), but is powerless when ignorance is lurking and unpredictability is omnipresent.

Irreversibility

Irreversibility is an intangible and little used (hidden; non-visible) concept. This mere observation is not a sufficient argument to condemn it as unimportant or irrelevant. Living hidden is often the sort of intangible but highly relevant phenomena and values. To my knowledge the social, economics, policy literature has no clear definition of the concept irreversibility. Neither there exists general acceptance of importing the irreversibility concept from the life sciences (thermodynamics).

As a definition I proposed: "*Reversibility is the ability to restore/ maintain the functional performance of a system*" (Verbruggen, 2011). Implementation of the definition requires demarcation of the system considered, and identification of the system's relevant functions and of appropriate performance indicators. An important corollary is that irreversibility is defined to come in degrees as an index from 0 to 1. This leaves behind us the rather trivial, digital 0/1 world of NO/YES (full) irreversibility.

For substantiating the irreversibility concept and for assessing its metrics, three variables qualifying and quantifying the impacts of decisions are needed:
1) *Duration* of the impacts that may last years, decades, centuries, up to … perpetuity (infinity); 2) *Reversal costs* to be made for restoring a disturbed functional state or for maintaining the state (or resilience of the system) that is threatened by irreversibility inducing developments; 3) *Substitutability* is whether a destroyed or heavily affected object, subject, or system can be replaced by an identical copy or by an acceptable similar exemplar. In practice there are cases where substitution occurs seamless, others where it is feasible although not fully satisfactory. But when absolute uniqueness prevails substitution is by definition precluded.

Assessing a degree of substitutability depends on the emphasis placed on the opposite poles of a dual property all subjects, objects, systems, etc. own, on the one hand: their identity – on the other hand: their role (functional performance). A clear example is offered by the human life – yours and mine. When considering a particular person, this subject owns a "strict identity", making her/him unique – in particular for her/himself and to some degree to her/his family members, friends, colleagues, … and there it mostly stops. For the rest of the world (the almost 7 billion people) that particular person has only functional meaning: as a student, a professor, a pilot, etc. What is accepted as being substitutable and to what degree is clearly contingent on the position of the decision-maker. For yourself loss-of-life is the end of your being (at least on earth, for people believing in spiritual life beyond death); for society your functional role will be taken over by another person (society even needs that life cycles roll, and that generations are renewed).

The three variables – duration, reversal costs, and substitutability – substantiate the concept of irreversibility and provide a framework for assessing its degrees. Duration and costs are cardinal variables; substitutability is ranked on an ordinal axis. The mixed cardinal-ordinal metric of irreversibility supports a gradation of irreversibility degrees from flexibility, over rigidity to preclusion zones.

Irreversibility in Life Sciences [Thermodynamics[1]]

The life sciences (with thermodynamics as core) provide more established and solid ground for studying irreversibility than the social sciences do. Engineering thermodynamics starts an energy/ entropy analysis with the basic exercise of delineating the studied system from its environment. The environment is the complement of the system; together they make up a relevant sub-universe[2]. Boundaries between system and environment are neatly identified and transfers in and out are accurately inventoried. Systems are isolated when no exchange whatsoever with the environment occurs. An isolated system is left over to only internal changes that according the second law of thermodynamics are irreversible: spontaneous changes bring the system in a state of higher entropy (lower quality) that never will spontaneously reverse to previous states of lower entropy (higher quality).

Isolated systems on earth are by definition of no practical economic interest. Humans get value from systems that interact with their environment. Natural systems do it without anthropogenic interference, for example plants use the soil and climate to thrive. To perform their intended functions, human driven systems require deliberate inputs of high-quality (low-entropy) matter-energy from the environment and discard low-quality (high-entropy) matter-energy to the environment. Overall, adding system and environment together to a relevant sub-universe, total entropy is always on the rise, i.e. irreversibility is ubiquitous and inevitable (no "perpetual motion" exists). This finding supports the existence of ultimate limits to growth, and triggers eschatological worldviews in the popular literature.

The seriousness of irreversibility depends on the quantitative and qualitative proportions of the system to its relevant sub-universe as metaphorically described by Boulding (1966). Qualitatively, the flows from system to environment should be assimilative by the environment (it means: avoid chemically toxic and persistent materials like for example Plutonium). Quantitatively even small flows of noxious/ dangerous materials may create irreversible impacts on the environment, but it is also known that even necessary and beneficial materials (for example carbon dioxide; organic nutrients like nitrogen and phosphate) when they are released/ exhausted in massive amounts create irreversible losses in life support systems (climate change; loss of biodiversity).

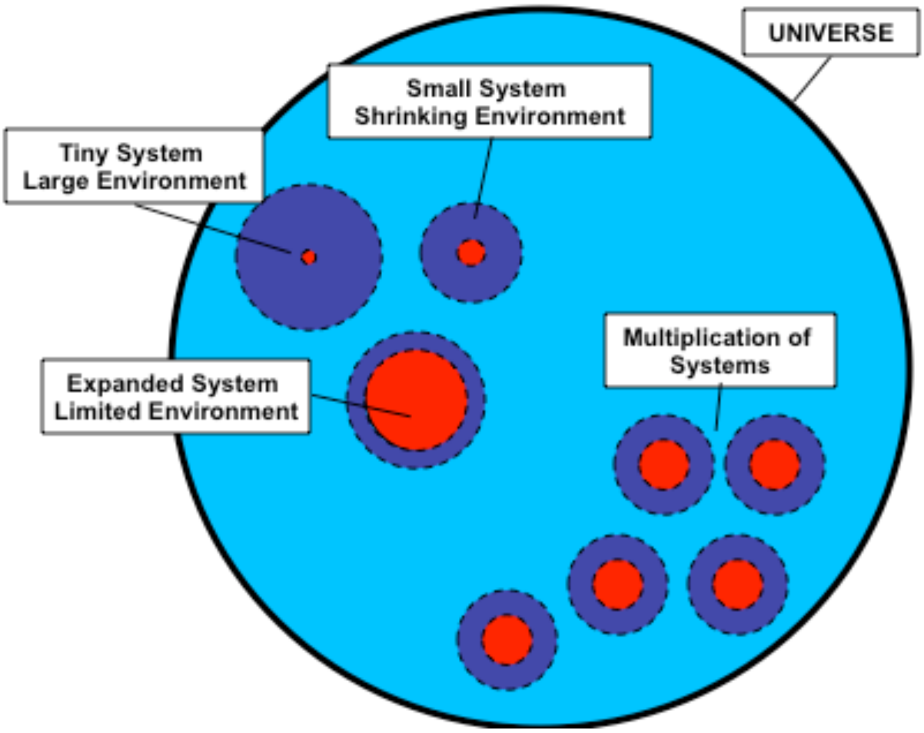
When a system grows to the size of its sub-universe and so both overlap, the system becomes an isolated one, and irreversibility has evolved to an absolute phenomenon. There are historic examples of local and regional over-exploitation of natural resources that created desserts, arid land, poisoned watersheds, contaminated habitats, etc. In some cases when the affected environment is indeed small and isolated from the whole universe, it may be irreversibly affected by the working of the system. In most cases the problems of local deterioration are addressed, and for a foreseeable future solved, by importing to

[1] I refer to engineering thermodynamics (Reynolds and Perkins, 1997), not to theoretical physics.

[2] When system + environment are but a part of a larger universe, the term sub-universe is used. For humankind the relevant ultimate universe is the earth-sun-moon constellation, with the sub-system earth as the only sub-universe where humans can thrive, mainly thanks to the daily solar influx.

the nearby environment high-quality matter and energy from the surrounding universe.
When the system is a tiny part of the sub-universe and the exchanges of matter-energy are tiny flows with moreover discarded flows easily assimilated by the environment, the functional quality of the system can readily be maintained for indefinite time. As long as there is no overlap between system and sub-universe, there is some degree of reversibility to restore a disturbed system. Therefore irreversibility is mainly a relative attribute of a system and its development. Irreversibility is no digital category but comes in degrees, depending on the scope of the studied system in relation to the sub-universe it is embedded in, and to the proportion of the sub-universe to the ultimate universe. Systems-environments-universe are relative and cascaded, at least as long as the dimensions of systems are not mushrooming up to the size of its environments, and both expand up to the size of the universe. In that case irreversibility is outgrowing to an absolute phenomenon. When getting absolute the life of the system is no longer sustainable because no longer an environment/universe is available for supplying the necessary high-quality sources and absorbing the low-quality residuals.

Figure 4: Stylistic examples of systems-environments-universe proportions

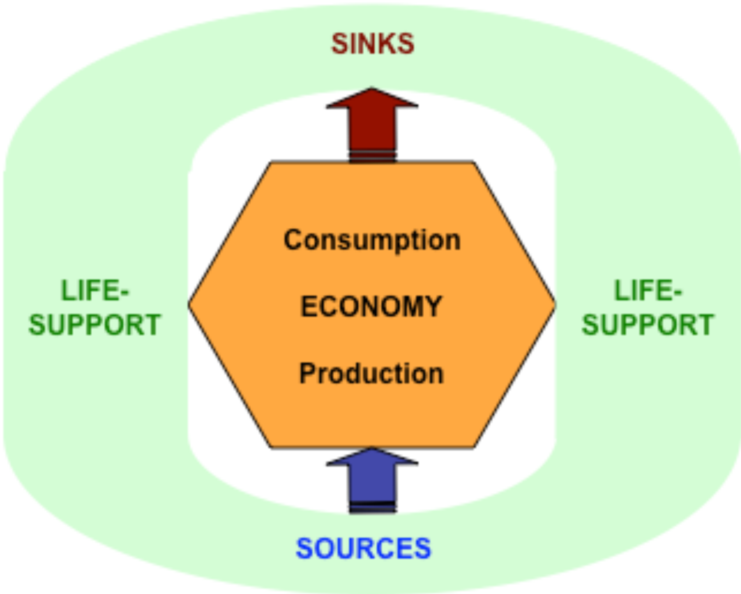


Irreversibility ranges from negligible (miniscule, assimilative flows), over serious (globally spread, enduring impacts) to absolute (system overlaps sub-universe, eventually the ultimate universe). Figure 4 provides a graphic view on a number of system-environment-universe relationships.

Economics and Irreversibility

Ecological economics (Ayres et Warr 2009; Daly 1973) have adopted the system-environment framework of the life sciences. This is the vision of the economic system as a metabolism within the natural environment; production is described as the anabolism and consumption as the catabolism (figure 5). The focus has shifted from (exhaustible) sources and (polluted) sinks to (degraded and endangered) life-support systems, although all are intertwined in the earth's single natural environment.

Figure 5: Economic metabolism living from its natural environment



This application delivers a conceptual framework for arguing limits to growth, but integrating thermodynamics and economics in operational models remains problematic. In ecological economics irreversibility is also related to phenomena like hysteresis[3], resilience, collapse, catastrophe, etc. Irreversibility inducing

---

[3] Hysteresis is the retardation of effects when acting driving forces are changed (reverted), observed in for example electromagnetism; in biological and ecological systems hysteresis expresses that "even after a long time, the state of a system may be partly determined by its history" (Ludwig et al., 1997). Resilience, also a basic concept in ecology (Ludwig et al., 1997; Perrings and Brock, 2009), expresses the ability to absorb perturbations without flipping to some alternate state or to recover from or adjust to misfortune or change. Both concepts contain referencing to irreversibility. Other factors that limit the return to initial states are decay and aging in mechanical and in biological systems (Boulding, 1966).

developments are expected to occur in the environment of the economic system, largely triggered or occasioned by inappropriate economic demands on the sources and sinks of the environment. However, ecological economics has but a modest voice in the chorus of economic disciplines, hardly heard when finance and industry shout.

Irreversibility is unevenly used and not well defined in mainstream economics. As dimensions, time and reversal costs are recognized (Dixit and Pindyck, 1994), but substitution among goods, services, factors of production and technologies is assumed to be widely (if not perfectly) feasible. Economics argues that price can reflect anything's value; then anything is tradable, exchangeable and in this way substitutable. One may oppose that actual physical objects, technologies, assets, values, etc. are less substitutable than the extent of the markets suggests. However, when engaged in exchange processes limits on physical substitutability are taken into account by higher market prices expressing tougher scarcity when some goods are less substitutable.

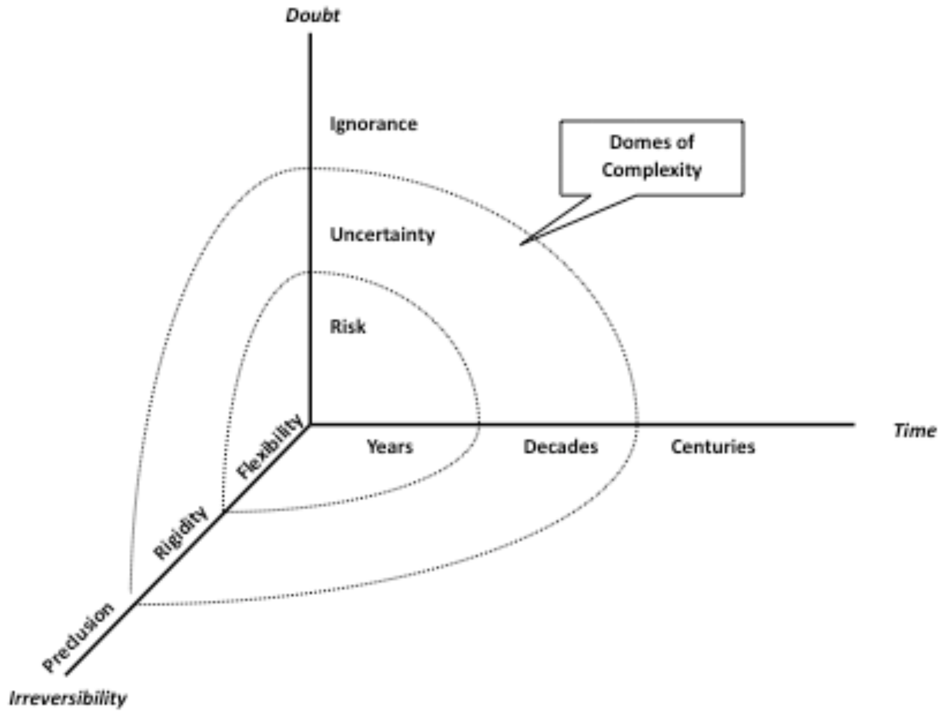
Decision space and Cost-Benefit Analysis

Cost-benefit analysis (CBA) is the general approach for framing and supporting societal decision making by economists; for example Nordhaus (1994, 2007) on the economics of climate change and climate policy. Monetizing all (or as much as possible) uses of economic resources in production and consumption activities is the goal of CBA. When accepting that all values can be monetized, substitutability is of minor concern. Irreversibility, if at all considered, is reduced to irrevocability of reversal costs (Verbruggen 2011). Discounting is the applied mathematical operator to process future time.

Figure 6 shows the decision context space made up by three dimensions: time, doubt and irreversibility. The complexity of a decision grows with every up-scaling of one of the dimensions. Within the dome of low complexity around the origin decisions are not that difficult to analyze and argue: discounting works well for periods of an overseen number of years, risks are manageable and affordable, and flexibility is an amenable degree of irreversibility. Cost-benefit analysis provides satisfactory services.

When years shift to decades, risk to uncertainty, and flexibility to rigidity, more unsolved issues are faced, and implementing cost-benefit analysis is no longer a technical task because many subjective choices are due. Beyond that medium complexity dome and in the outer of the decision space, cost-benefit analysis falters. Weighting values across centuries, prospecting the abyss of ignorance and imagining suitable responses, degrees of irreversibility precluding important options in the future, requires analytical tools and architectures for agreement of a different nature than available and applied by cost-benefit schemes. Public decision makers should arm society to face unpredictability by giving preference to flexibility, robustness and resilience above preclusion and direct financial gains (flowing mostly to the ones that own already most).

Figure 6: Time, Doubt and Irreversibility make up the decision context space



References

Ayres, R.U., Warr, B., 2009. The Economic Growth Engine. Edward Elgar, UK.
Boulding, K., 1966. The economics of the coming spaceship earth. Environmental Quality in a Growing Economy. Resources for the Future, pp.253-263 in Daly, H.E., ed., 1973. Economics, Ecology, Ethics. Essays toward a steady-state economy. W.H. Freeman and Company, USA.
Dixit, A.K., Pindyck, R.S., 1994. Investment under Uncertainty. Princeton University Press. Princeton, New Jersey
Ludwig, D., Walker, B., Holling, C.S. , 1997. Sustainability, Stability and Resilience. Conservation Ecology 1 (1), art.7 (online: www.consecol.org/vol1/iss1/art7/)
Matheson, J.E., Howard, R.A., 1968. An Introduction to Decision Analysis. Stanford Research Institute, Menlo Park, CA, USA.
Nordhaus, W., 1994. Managing the Global Commons: The Economics of Climate Change. MIT Press, Cambridge.
Nordhaus, W., 2007. The Challenge of Global Warming: Economic Models and Environmental Policy. Yale University, New Haven, USA
Perrings, C., Brock, W., 2009. Irreversibility in Economics. Annual Review of Resource Economics 1, 219-238.
Portney, P.R., Weyant, J.P., eds., 1999. Discounting and Intergenerational Equity. Resources for the Future, Washington, DC
Reynolds, W.C. and Perkins, H.C., 1977. Engineering thermodynamics. McGraw-Hill Book Company, USA.
Simmons, I.G., 1989. Changing the Face of the Earth. Culture, Environment, History. Basil Blackwell, UK.
Stirling, A., 1999. On science and precaution in the management of technological risk. SPRU, University of Sussex.
Taleb, N.N., 2010. The Black Swan: The Impact of the Highly Improbable. Random House, USA.
Verbruggen, A., 2011. Revisiting Irreversibility: concepts and metrics. University of Antwerp, mimeo, submitted for presentation at EAERE conference (Rome, June-July 2011).