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Risk Beyond Repeated Games – Extreme Events, Intertemporal Decisions and Resilience

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Abstract

End of the 17th century/beginning of the 18th century, the basic calculus of probability was developed from a perspective of gambling, i.e. assuming 'repeated games' with continuously ongoing processes. Vice versa, contemporary question of risk management address more and more singular events: from extreme events in operational risk management in banking to climate-change risk and risk of new technologies such as artificial intelligence.

This perspective 'beyond repeated games' is briefly summarised in this paper: starting from the methodology of extreme value theory to the sociological issue how 'risk' a regarded in today's society – especially when it comes to singular situations of decision-making under uncertainty and the question of incentives.

Finally, the challenge of intertemporal decisions and long-term resilience for the case that disruptions might have happened is reviewed, which asks the question how to evaluate decision-making with current costs but benefit or damages, which will materialize in the future. This question points to the issue that any risk 'beyond repeated games' is depending on the societal context and can change depending on the external observer.

All-in-all, contemporary risk management has to look beyond the situation of ongoing processes to situations of limited experience and missing strength-of-knowledge, in which decision have to be made, nonetheless.

Mit speziellen Dank und besten Wünschen an Prof. Wolf Wössner.

Inhalt

1. Introduction

After decades of discussion about risk management in banks it has to be asked, why do I write another contribution about risk? The success of risk management comes with the concern that we a used to regard risk from a perspective of 'repeated games' – i.e. ongoing stochastic processes with independent and identically distributed events (IID) – and of normal distribution or, more generally, statistical distributions with defined mean values and higher moments.

On the one side, this is a very strong assumption and – vice versa - limitation, if presumed for any estimation of the future in cases of decision-making under uncertainty. On the other side, we see many current challenges, which are rather singular – from rare, but severe events in operational risk in banking to climate-change risk and regulatory risk for the financial services industry.

While 'fad tail' events can methodologically be handled by extreme value theory (EVT), there is a cognitive mismatch between our human expectation of linearity and repeatability and the reality of an uncertain future. This challenge is far from being new, and already Medieval merchants developed approach to tackle this 'risk' resulting from free individual decision under uncertainty.

The more statistical risk management developed, the more we tend to believe in our own models and implicit assumptions. To avoid the pitfalls of mindcuffs, this paper will briefly summarize a concept of 'risk beyond repeated games' and especially intertemporal decision-making under uncertainty. This perspective on 'risk' reveals that – independent of the mathematically calculus of probability – 'risk' has also an important societal aspect about 'risk taking' and responsibility.

Consequently, this paper starts with a definition of 'risk' and the question about our human 'strength-of-knowledge' and a historical review of the development of the concept of 'Risicum & Periculum'. Afterwards, the mathematical methodology of 'fat tails and power law, the question of time' and the matter of 'expected utility of tail events' are discussed. Subsequently, the societal perspective on 'risk' is considered with special regard to adaption and intertemporal decisions-making. Finally, a closer look is taken on the physical processes underlying 'risk', and two examples of climate-change risk in banking and the new point of view about credit scoring as a 'high-risk' application in a current proposal of the European Commission are elaborated in detail, before coming to a brief conclusion.

2. Risk – Definition and the Strength-of-Knowledge

The current definition of 'risk' as codified by the International Organization for Standardization in ISO 31000 is '*the effect of uncertainty on objectives*' (Purdy, 2010). However, this is not the end of a century-long development, as especially Terje Aven (2017) articulated in '*The flaws of the ISO 31000 conceptualisation of risk*' and the Society for Risk Analysis (SRA, 2018) elaborated that the ISO definition can be interpret in many different ways.

Of course, there are differences between risks in gambling ('put all money on three times "6"'), in a credit decision (with expected/unexpected losses due to future default, but also incorrect assumptions as in the U.S. sub-prime crisis about 'independence' of events) or concerning the preparation for 'recovery of operations after a (at this time unknown) disruption of service' in the future. However, these examples make clear that 'risk' is always connected with a human <u>decision-making under uncertainty</u> with regard to the future consequences of our decisions and in the context of our objectives. While natural events – from quantum-mechanical nuclear decay via deterministic non-linear systems to complex formation of patterns such as a hurricane – come with 'probabilities', any 'risk' is always regarded from the perspective of our expectations and, consequently, linked to human knowledge.

Both, the difference between probability and risk and the background of human knowledge, has been discussed since the second half of the 17th century/beginning of the 18th century, when the calculus of probability was developed based on ideas about gambling by the Chavalier de Méré, Christiaan Huygens, Gerolamo Cardano, Jakob Bernoulli, Abraham de Moivre and others. Abraham de Moivre (1718) wrote in his book on 'The Doctrine of Chances: Or, a Method of Calculating the Probabilities of Events in Play [quote]:

> *The Risk of losing any Sum is […] the product of the Sum adventured multiplied by the Probability of the Loss.*

This is – still – the understanding of 'risk' in financial risk management with the simplification of: 'Risk = potential Loss * Probability'. Unfortunately, the main underlying assumption and the context of this original understanding is often ignored: The calculus of probability of the 18th century was developed for <u>repeated games</u> only.

In other words, the calculus of probability assumes IID events, which are independent and identically distributed: the outcomes we get from the flipping of a coin does neither depend on coins flipped before and does not depend on whether we do it now or anytime in future. This includes another assumption of '*stationary ergodic processes*', i.e. random processes generating the outcome (like flipping of a coin or rolling the dice) with time-independence and statistical properties, which are deducible *ex-post* from any sufficiently long sample.

The concept of '*sufficiently long sample generated by a stochastic process*' was continued within the modern mathematical formalism, for which Andrei Kolmogorov (1933) laid the foundation with his work about '*Grundbegriffe der Wahrscheinlichkeitsrechnung*', where he and also Bruno de Finetti (1938) discussed the features of time series. Even more extreme, Bruno de Finetti elaborated that 'change' does not exist at all, because every series of events with the same number of rolling the dice is equivalent – the sequence is not important, but only the frequency of events, what Bruno de Finetti called '*exchangeability'*.

However, there are rare events – from the unexpected correlation in U.S. subprime mortgages via riverine flooding in Germany with extreme events once in hundred years to Putin's hybrid attach with an aggressive war on Ukraine and an energy war on Europe – for which one or all of these assumptions do not hold true. Vice versa, any discussion of rare extreme events – i.e. very low frequency but very high severity – requires a more general approach beyond 'repeated games'.

Therefore, 'risk' could be defined by (cf. Terje Aven, 2010, 2012, 2020 and Udo Milkau, 2017, 2021, 2022):

$$Risk = \{E, C(O), P(K)\} \tag{2.1}$$

for a future Event E (or class of similar events)
with a Consequence C (a Loss L, a Damage D or a reduction of Performance P[1] in a time interval Δt from t_1 to t_2) related to an Objective O
and Probability P as an estimation of the frequency, which is dependent on the Knowledge K that supports C and P and includes a judgement about our Strength-of-Knowledge (SoK).

[1] The problem that risk can be a single event but also a reduction of a system performance over an interval Δt from t_1 to t_2 is discussed in Aven (2021).

It is important to remark that (i) the Probability P does not require a sample of previous evens but could be calculated from underlying processes such as see level rise leading to the consequence of flood peaks over the threshold of existing dikes for example and (ii) there is *no risk without an objective*, as an economic objective function, a social agreement, or a political vision are required as benchmark.

With this general definition, a sequence of specific definition can be developed, which follow along a line of decreasing Strength-of-Knowledge.

► **Frequency of Recorded Events (with a loss)**

$$R_0 = \{E_r, L, P_f; SoK{=}1\} \tag{2.2}$$

for N recorded Event E_r with a respected Loss L and frequency-dependent *ex-post* Probability P_f. For aggregated recordings with separated binning i also the Variance σ_i can be included:

$$R_I = \{E_i, L_i, N_i, \sigma_i; SoK{=}1\} \tag{2.3}$$

Trivially, the Strength-of-Knowledge for recorded 'known' events is always SoK=1. For aggregated data within bins, the variance represents the statistical error of the measurement (especially driven by noise, i.e. external effects on the measurements). This statistical uncertainty – or fluctuation in measurements – has to be distinguished from any epistemological uncertainty SoK <1, which stands for our limitations of human knowledge to predict future developments (for example with models).

► **Subjective Probabilities (the Bayesian perspective)**

$$R_S = \{E, L, P_S \mid A; SoK_A{=}1\} \tag{2.4}$$

with a Bayesian interpretation of probability Ps as a subjective measure of uncertainty given that Assumption 'A = true' and thus related to the subjective knowledge with $SoK_A = 1$.

An assumption can be, for example, a continuously running random process, i.e. a 'repeated game' with recurring events. In such a stationary, ergodic process with random, independent and purely statistical events, the statistical properties can be derived from a (sufficiently long) measured time series of events. While in gambling such as dice or roulette, repeatability is given as a 'fixed rule of the game' (and thus $SoK_A = 1$). However, this is true as long as no one breaks the rules, and any repeatability is a subjective assumption! Such a subjective assumption could be a 'model risk', if not well articulated.

The wrong induction must be avoided, according to which what often happened will continue to happen: Turkeys have a good live for many, many days - until Thanksgiving. The believe to derive causal statements about the future based only on correlations in data from the past is unreasonable without a causal model or without specified assumptions (cf. Popper, 2021 and Pearl, 2018).

► **Parameter-dependent Risk (with an exogenous impact)**

$$R(x)_S = \{E, L, P_S \mid A; SoK_A=1; x\} \quad (2.5)$$

as an extension of the Bayesian interpretation with dependence on an external control parameter.

This case is often underestimated but could introduce a dangerous bias. This can be illustrated with two examples:

1. Dependence of Operational Risk on Interest Rates

A significant part of Operational Risk loss events are delayed processes (such as payments or corporate actions) with customer claims for compensation of the lost interest. If the interest rate is changing within the recorded timeframe, this has to be included as an external control parameter. For the same loss event – say: three days of delay of a payment – different interest rates result in different losses, but with same root causes and same underlying processes. Especially as one uses lower reporting thresholds in Op. Risk management, a decrease of interest rate results in a lower number of reported incidents due to this static cut-off threshold for dynamic time-dependent shifts (Arlt et al., 2013).

2. The Expanding Bull's-eye Effect

The so-called 'expanding bull's-eye effect' is a very illustrative example for the difference between an incident event (e.g. a natural disaster like hurricanes or coastal / riverine flooding) and the loss (especially fatalities and economic damages). The total damage of an event can be split into:

$$Damage(t) = Severity_E * Density(t) * Value(t) \quad (2.6)$$

As typically financial damages are recorded, the Damage D depends on the Severity S of an event but also on the Density D of the population in risk-prone areas (coastal regions or river valleys) and the Value V of houses and other goods. While the frequency of events is often constant, much more people with much more value moved to these regions over time: i.e. they populated the 'bull's-eye' (Lomborg, 2020; Tellman, 2021; Lomborg, 2021). Vice versa, recorded increase of damages – such as in insurance data – may not be caused by more frequent or more severe events, but by more people deciding to life in risk-prone areas, especially when natural disasters occur on time-scales of decades or even centuries.

► **Estimation of future Risk (especially for decisions under uncertainty)**

$$R_F = \{E, L, P, U(P); SoK<1\} \quad (2.7)$$

with the Uncertainty U(P) about an estimation of future probabilities (i.e. future frequency and severity distributions) based on our limited Strength-of-Knowledge concerning the future.

This definition differs fundamentally from the previous ones, as the focus is on the uncertain development in the future. This perspective of 'risk' is linked to decisions under uncertainty, as in a world of 'repeated games'. Without a human decisions, the estimation of a future risk beyond simple statistics is irrelevant. In a zero-sum game, for example, we know that nobody can win in the long run.

However, this is the first definition of 'risk', which explicitly assumes our limited Strength-of-Knowledge and, consequently, our uncertainty about the 'repeatability of the game' and about the underlying processes in general. This would be the major step forward for any turkey to avoid the surprise of Thanksgiving.

► **Uncertainty to Achieve (risky) Objectives**

$$R_U = \{E, O, U(SoK<1)\} \quad (2.8)$$

with an Uncertainty U depending on our Strength-of-Knowledge.

Although this may look like a simple replacement of P by U, this is a shift of paradigm from an *ex-post* analysis of the frequency of recorded events to an *ex-ante* uncertainty how to achieve the planned objectives. One can apply process scenarios or counter-factual simulations to estimate this type of risk.

However, any (helpful) estimation should not result in a control illusion and too much believe in *ex-ante* planning exercises[2]. The more we enter the regime of limited Strength-of-Knowledge, the more carefulness is required to manage future events step-by-step with a continuous reconciliation between assumptions and reality and, consequently, capability to adapt to changes or new experiences.

► **The 'Once in a Lifetime' Events (with a breakdown of critical functions)**

$$R_B = \{E, F(O), SoK << 1\} \qquad (2.9)$$

with a Breakdown, Failure or Outage of a critical Function (with Objectives O) and a very limited Strength-of-Knowledge due to missing experience, oblivion of 'old' experiences and/or confirmation bias based on a pre-selection of events 'we want to see'.

This case reveals an overlap of statistics of rare events with cognitive biases (see especially Tversky and Kahneman, 1974 and Kahneman and Tversky, 1996), which requires a careful treatment what we 'want to see' as rare events. Three examples illustrate different aspects:

1. Dependence on Reporting Thresholds and Duration of Measurement

As already mentioned before, in Op. Risk management the recorded probability distributions of loss events suffer from a reporting cut-off as a lower threshold. At the other end of low-frequency/high-severity events the duration of measurement has an impact, how many events are recorded as so-called 'tail events'. Both effects together can distort fits to the recorded data, as the mid-range will be given more weight – but due to 'missing' data at both ends – and a 'peak' could result as an artefact. This will be discussed in detail in the chapter about 'power law' distributions.

2. A Culture of Obliviscence (originally: '*Kultur des Vergessens*')

In summer 2021 the German river valley 'Ahrtal' suffered from a flooding catastrophe with – sad to say - many fatalities, enormous economic damages, and a failure of civil crisis management. However, it is important for our future action concerning climate-change risk to look to statistics.

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[2] This is mirrored in military leadership with the difference between binding 'orders' (based on *ex-ante* planning of future actions) and the concept of '*Auftragstaktik'* (translated into 'mission command' and to be compared with 'Befehlstaktik'), which defined objectives (sic!) to be achieved in an adaptive way with constant monitoring and flexibility.

A first calculation for such an extreme riverine flood by the World Weather Attribution (Kreienkamp et al., 2021) project found that [quote]: ‘*At the Ahr river the flood is estimated to be a 500 year event or rarer …‘* and *‘In a climate 2 °C warmer than in preindustrial times models suggest that the intensity of a 1-day event would increase by a further 0.8-6% and the likelihood by a factor of 1.2-1.4.*’ These estimations were based on an analysis of ‘official’ weather data with time series of daily accumulated precipitation since 1930 (i.e. 90 years of data vs. frequency of 1-in-500 years). Based on a newspaper article (Staib, 2021) it was rather easy to find older data in two reports in the annual yearbooks of the Ahrtal county of 1955 and 1983 (‘Heimatjahrbuch’; Frick, 1955 and Seel, 1983). These reports analysed old written records – i.e. ‘analogue’ data – and revealed that floods of similar or nearly similar magnitude occurred in 1804 and 1910 even before global warming. These data indicating some regularity on a 1-in-100 year timescale were not taken into account in all analysis of ‘digital’ weather data. Unfortunately, people settled in areas known as flood-prone in former centuries. Thomas Roggenkamp, a scientist with a master thesis on ‘*Rekonstruktion historischer Hochwasser der Ahr’*, was quoted in the mentioned newspaper article that there is some collective ‘culture of obliviscence‘ (‘*Kultur des Vergessens’*) in regions, which have been exposed to climate risk with disasters that may happen once in a lifetime or even less frequent.

3. Selection Bias

One example for selection bias can be the 2011 nuclear accident at the Fukushima Daiichi Nuclear Power Plant, which is used often to qualify nuclear power production as inacceptable ‘high risk’. The root cause of the nuclear disaster was the 2011 Tōhoku earthquake, which was the most severe earthquake ever recorded in Japan, and the following tsunami on 11 March 2011. From the point of view of statistics two issue are important: In many debates, the Fukushima disaster is linked to the number of approximately 20 000 fatalities. However, these unfortunate fatalities were caused by the earthquake and the tsunami, i.e. natural disasters (plus few accidents during the evacuation of the county). According to the last report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2021) there was no direct death from the leaked radioactivity of the nuclear disasters.

Additionally, there were five (sic!) nuclear power plants at the East coast of Japan, which were affected by earthquake and tsunami: Higashidori, Onagawa (with successful resilience, see: Ibrion et al., 2020), Fukushima Daiichi, Fukushima Daini, and Tokai Daini – but only one nuclear meltdown. Finally, the Fukushima Nuclear Accident Independent Investigation Commission (NAIIC, 2012) concluded [quote]: *'The TEPCO Fukushima Nuclear Power Plant accident was the result of collusion between the government, the regulators and TEPCO, and the lack of governance by said parties. They effectively betrayed the nation's right to be safe from nuclear accidents. Therefore, we conclude that the accident was clearly "manmade." ... The direct causes of the accident were all foreseeable prior to March 11, 2011*.' In other words, the root cause was not the technology, but that the technology was implemented wrongly and illegally.

► **The 'Unknown Unknown' (unexpectable disastrous events)**

$$R_{Disaster} = \{E, \text{not } F(O), SoK = 0\} \qquad (2.10)$$

For some disastrous event disrupting a critical Function (with Objectives O), which we cannot anticipate, because we have not knowledge at all – even not an any science fiction story.

Typically, such an 'unknown unknown' is regarded as 'Knightian uncertainty' (Knight, 1921) with a lack of any quantifiable knowledge about some possible occurrence. His separation between the 'known' and the 'unknown' referred to the historical development of the calculus of probability with the consideration of 'repeated games' versus the probability of future events without any known underlying process. In reality, any 'unknown unknown' raises the question whether we cannot know (no data at all), we don't know (no measurement up to now) or we don't want to know (cognitive bias). While we understand aleatory uncertainty - or the probability of 'repeated games' – quite well, the regime of epistemological uncertainty is overlapping with cognitive bias[3][4].

[3] Even the image of a'Black Swan' does not fit for an 'unknown unknown'. The Roman poet Decimus Junius Juvenalis (in German: Juvenal) of the late first/early second century already wrote about '*rara avis in terris, nigroque simillima cygno*' (a rare bird on earth and similar to a black swan) and '*felix ille tamen corvo quoque rarior albo'* (such a lucky man is rarer than a white raven) for very rare human characters. Even long before the development of probability calculation, the idea of a black swan or white raven was by no means outside the possible imagination.
[4] The aspect of quantum-mechanical uncertainty will be skipped in this paper.

This concept of different ‘unknowns’ mirrors the idea of achieving an objective within a critical function. From this point of view, it does not matter what causes a disruption of operation: from missing scientific knowledge via wrong assumptions and ignorance to missing preparation. Whether the U.S. subprime crisis, the disaster in the Ahrtal, or climate change – nothing was ‘unexpectable’ scientifically but not taken into account by us as human beings. Consequently, any analysis of extreme risk events has to apply advanced statistics but as well behavioural science.

3. Risicum & Periculum – the Sociological Perspective

The challenge to face a 'risk' is as old as human history, and for more details about the historical development the reader is referred to the paper '*Risk Culture during the Last 2000 Years*' (Milkau, 2017). However, a brief overview is helpful for the discussion because understanding 'risk' depends on the historical and social context.

Mary Beard (2011) elaborated in her intriguing Darwin College Lecture about '*Risk and the humanities: Alea iacta est*.' The perception of what we call 'risk' was existing already in the Roman society [quote]:

> *Romans used the imaginary of dicing actively to parade (and so, in a sense, manage) uncertainty. […] the luck of the board game became a way of seeing, classifying and understanding what in our terms might be thought of as risk*.

The term 'risk' appeared in European languages at the beginning of the 16th century, and the first appearance in German was probably in 1507 as '*uff unser rysigo*'. In the classical Latin language only danger ('*periculum'*) or - with an ambivalent context like in gambling (sic!) - luck ('*fortuna'*) existed.

During the Italian Renaissance, a differentiation between roles and responsibilities in Mediterranean Sea trade and the emergence of 'individuality' resulted in a differentiation between:

- 'Risicum' was used in the context of <u>individual (commercial) decision</u> under uncertainty, but with the responsibility to accept or to cover the (financial) consequences and damages.
- 'Periculum' was used for <u>exogenous (natural) forces</u>, which the merchant could not be aware of, but could be covered by an insurance contract.

Benjamin Scheller (2017) described this differentiation as '*The Birth of Risk'* [quote]:

> *Mit der Entstehung der Seeversicherung im 14. Jahrhundert begannen italienische Fernkaufleute dann, übernommene Risiken immer genauer zu bestimmen, ... Die Zukunft hatte von nun an ihren Preis.*

However, there was no singular point in time as maritime sea insurance had developed since the 12th century (in Italy based on old Roman sea loan contracts), formalized between the mid of the 14th century and beginning 16th century including a shift of trade to Northern Europe, and adapting the modern calculus of probability from beginning of the 18th century.

The ‘Birth of Risk’ as an economic concept was based on three different shifts of paradigm in the Medieval and Renaissance merchant community[5]:

- A sustainable legal system with the concept of individual responsibility
- The economic development based on transregional markets and increasing commercial interdependencies
- Early scientific knowledge (in the sense of records and accounts of commercial transactions and the relevant parameters incl. route, captains’ ‘management abilities’, weather, events such as pirate attacks et cetera)

Nonetheless, the economic concept of ‘risk’ was a concept of individual decisions, actions, and consequences until the 20th century. The new philosophical development of ‘postmodernism’ reveals an attitude of scepticism towards scientific knowledge, a replacement of facts by a ‘discourse’ and a usage of the term ‘risk’ as part of critique of the modern society and market economy (see Box 1).

While ‘postmodernism’ is a contemporary phenomenon in Western philosophy, the public debate of ‘risk’ in the society is a general one. One can speculate what pushed ‘risk’ into the spotlight of societal discussion. At least a part of this development was triggered by the discussion about nuclear weapons and - in continuation - nuclear energy with the accidents at Three Miles Island and the Chernobyl disaster.

Two principles are characteristic for ‘postmodernism’: the denial of any objective knowledge and the mantra that the society is dominated by the power of language, i.e. the ‘discourse’ constructs the reality but no ‘measurable’ facts. This replacement of rational knowledge (with all limitations what humans can know) by subjective perception contradicts the definition of ‘risk’ in chapter 1 and introduces an arbitrariness, what somebody perceives as ‘risk’.

[5] Later, these developments were roots for the Great Enlightenment with a development of the whole society and tremendous increase of wealth and benefits for the whole population.

If one tries to analyse the awareness for ‘risk’ in modern societies, one milestone was the book of Ulrich Beck (1986) ‘*Risikogesellschaft. Auf dem Weg in eine andere Moderne*’. As already the title indicates, this book does not discuss ‘risk’ in general but develops an opinion about some ‘post-modern’ society. The preface clarifies [quote]:

The theme of this book is the unremarkable prefix 'post'. It is the key word of our times. Everything is 'post'. We have become used to post-industrialism now for some time, and we can still more or less make sense of it. ... To that extent, this book contains some empirically oriented, projective social theory - without any methodological safeguards. ... a break within modernity, which is freeing itself from the contours of the classical industrial society and forging a new form - the (industrial) 'risk society'. ... the immanent contradictions between modernity and counter-modernity within industrial society at the center of discussion (Parts II and 111). On the one hand, industrial society is planned as an extended group society in the sense of a class or stratified society yesterday, today and for the entire future. ...

Tis concept of a ‘Postmodern Society’ addressed ideas of the so-called French Theory of the 1950s to 1970s, which is represented by Michel Foucault, Jacques Derrida, Jean-François Lyotard and others.

Especially, Ulrich Beck continues the rejection of modern sciences and the scientific principle of models, hypothesis and falsification [quote]:

Falibilism in Research Practice … On the one hand, science's claim to be able to explain things has retreated to the hypothesis, the conjecture subject to recall. On the other hand reality has sublimated into data that are produced. Thus 'facts' - the former centerpieces of reality - are nothing but answers to questions that could just as well have been asked differently, products of rules for gathering and omitting. A different computer, a different specialist, a different institute - a different 'reality'.

This rejection of sciences was already pointed out by Jean-François Lyotard (1979), who distinguished between ‘scientific knowledge’ and ‘narrative knowledge’, refused the legitimation of scientific knowledge (regarded as ‘a language game’), and introduced a ‘narrative knowledge’ of traditional stories or personal impressions, which does not require any legitimation [quote]:

The object of this study is the condition of knowledge in the most highly developed societies. I have decided to use the word postmodern to describe that condition. ... Sciences has always been in conflict narratives. ...

Postmodern knowledge is not simply a tool of the authorities; it refines our sensitivity to differences and reinforces our ability to tolerate the incommensurable. Its principle is not the expert's homology, but the inventor's paralogy. ... Knowledge is not the same as science, especially in its contemporary form; and science, far from successfully obscuring the problem of its legitimacy, cannot avoid raising it with all of its implications, which are no less sociopolitical than epistemological.

It is therefore impossible to judge the existence or validity of narrative knowledge on the basis of scientific knowledge and vice versa: the relevant criteria are different.

Based on this concept of ‘postmodernism’, Ulrich Beck’s discussion of ‘risks’ of modern technology does not address technological features, but postulates ‘risk’ based on post-modern (non-scientific) knowledge and demands a ‘new modernity’.

Box 1: The position of postmodern theory against scientific knowledge

For example, Ullrich Beck used the term ‘risk’ to describe the effect of present problems such as pollution or environmental degradation on the society. The ‘risk’ of a sea merchant making individual decisions (about his next venture) is substituted by a societal discourse concerning safety of technologies from a political perspective (and disregarding the tremendous growth in health, wealth and safety due to the open market economy in the last 200 years).

The German sociologist Niklas Luhmann discussed this interaction of ‘risks’ and social awareness in his excellent book of 1991 about ‘*Soziologie des Risikos’*, from which (in the English version) the following quotes are taken:

> *Or even more fundamentally. How do we comprehend our society if we turn the concept of risk – once a matter only for mariners, mushroom-pickers, or other groups exposing themselves to danger – into a universal problem neither avoidable nor evadable?*
>
> *What is chance? How does society in the normal performance of its operations cope with a future about which nothing certain can be discerned, but only what is more or less probable or improbable?*
>
> *One aspect is especially worth noting: whereas individuals normally concern themselves only with probabilities of medium-range frequency, ignoring what is highly improbable, and on the other hand the highly probable (…) has been*

> *normalized, risk awareness today shows evidence of deviant circumstances, especially a fascination with the possibility of extremely improbable occurrences, which – when they do happen – constitute a disaster. … The explanation is likely to be that nowadays people or organizations – that is to say decisions – can be identified as the root cause. Without talking nonsense one can demand that such dangers be obviated.*
>
> *It may well be possible to calculate that the danger to which one is exposed by the existence of a new nuclear power station in the neighbourhood is no greater than the risk of deciding to drive a further three miles per year. The calculation is hardly likely to impress anyone, since in the one case the problem is perceived as a disaster and not in the other; and also because the aptness of quantitative analysis to manipulation is notorious.*
>
> *In fact quantitative analysis always becomes irrelevant where disasters are to be feared. What is to count as a disaster is not decided on the basis of objective criteria. ... [Die Katastrophenschwelle] disaster threshold is set in very different ways by the politically relevant population and above all by the mass media, and it will prove difficult to obtain agreement even on borderline cases - because it is precisely here that the exact delimitation of the loss falls within the zone of the uncertain.*

Without going into details, these few quotes by Niklas Luhmann illustrate, how the conceptualisation of ‘risk’ depends on the historical and social context. Today – three decades after Nilkas Luhmann’ book – the public debate is dominated by a *Zeitgeist* of 'post-everything', which demands 'radical' changes but lacks the connection to reality with statements like:

‘The crisis is the new normal.’

Independent from the question about semantic meaningfulness, this statement underlines how much any discussion about risk, crisis or resilience is embedded in the contemporary perception about the state of the society. Already Niklas Luhmann discussed the issue of ‘risk in the social context’ and the difference between a decision-making (under uncertainty) and the observation of this process by social agents. His framework is illustrated in the following figure (Fig. 3.1).

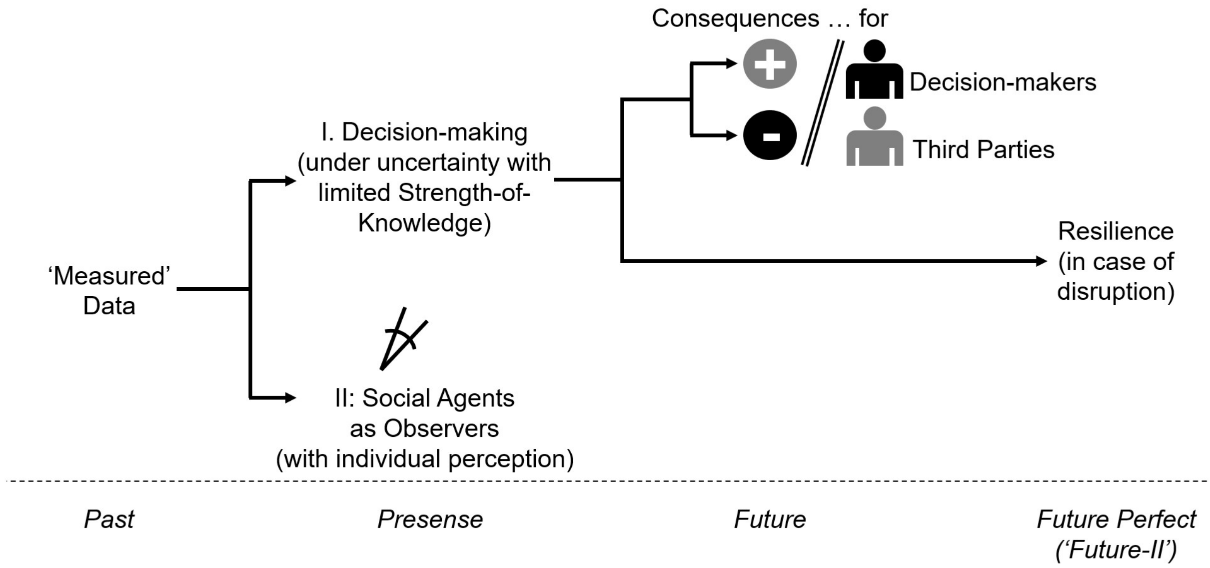

Figure 3.1: Framework to evaluate 'risk' along the timeline (incl. Future-II). The 'Consequences … for' should indicate that a decision can have positive as well negative consequences for the decision-maker and/or third parties.

In this stylized case, on the one hand a decision-maker has to act under uncertainty and is responsible for the – positive or negative – consequences, which can affect the decision-maker and/or a third party[6]. On the other side social agents observe this process, but might have very own intentions and perceptions, which are not necessarily based on objective data ('measured data'). Additionally, there is the challenge that things might go wrong, and a disruption (of critical operations) have occurred despite all measure to avoid such consequences. This issue will be discussed later on.

[6] For the problem of ‚the Commons' the reader is referred to the summary of Elinor Ostrom (2012). In this booklet the problem of 'free-riding', e.g. maritime vessels benefiting from lighthouse services, which are often financed by near-by harbour companies taking charges for port usage, is discussed and – typically – polycentric systems of governance can provide solutions. Vice versa, a potential future damage can affect third parties.

4. Fat Tails, Power Law, Cognitive Bias and the Question of Time

There is a remarkable book by Persi Diaconis and Brian Skyrms (2018) about the historical development of the calculus of probability: '*Ten Great Ideas About Chance*'. While this book is very helpful for insight into the history of 'chance', it tells the story of repeated games, ergodic processes, IID events and The Law of Large Numbers (or in German: *Zentraler Grenzwertsatz*), which was developed in an early version by Jakob Bernoulli (1655–1705) within his masterpiece '*Ars Conjectandi*'. As a – much simplified – consequence, the normal or Gaussian distribution became the underlying (unconscious) assumption of applied statistics. Even in cases of non-symmetric probability distribution like in credit risk management, well-behaving features (with normalization to unity and finite mean value et cetera) are expected.

This bias can be illustrated by a quote from a working papers of Dutta und Perry (2006) about tail risk: '*A tale of tails*' [quote]:

> *Here, we observed that even when many distributions fit the data they resulted in unrealistic capital estimates (sometimes more than 100% of the asset size), primarily due to their inability to model the extremely high losses accurately. …*
>
> *… power law variant … fit well in some statistical sense but gave reasonable estimates for just two of the seven institutions at the enterprise level.*

Of course, well-behaving probability distributions can be easily calculated and provide result with finite aggregated losses - and further finite regulatory capital. However, one can ask, whether every probability distribution has to be 'easy'?

Already in the 1960s, Benoît B. Mandelbrot discussed 'fat tails' in market data and pointed out the problems of 'fat tail risk'. In the great summary, Mandelbrot (2001) also discussed power-law distribution of financial price changes, which can be [quote]:

> *… written as $Pr(U > u) \sim u^{-\alpha}$. The key question is whether or not the exponent α is restricted to $\alpha < 2$.*

This is important, as for $\alpha < 2$ there are neither finite means nor finite higher moments. For other types of 'operational' risk, it has been well known for decades that disruptive processes – leading to 'fragmentation' - might follow power law statistics with $\alpha < 2$ (see e.g. Milkau, 1991). What's the problem with $u^{-\alpha}$ and $\alpha < 2$:
It has no finite mean value – e.g. for calculation of economic capital!

Switching to operational risk (due to failed processes in banks et cetera), a detailed analysis of various loss data collections can be found in a staff perspectives paper of the Japanese Financial Services Agency from 2011 (Nagafuji et al., 2011). In particular, the authors had analysed three data collections: the loss data of 18 Japanese banks, the LDCE2008 collection for 118 banks of the BIS (2009) and the LDCE2004 collection of the U.S. Federal Reserve Bank (Fed Boston, 2005), as well as older data with the same approach.

They fitted the parameter λ of a Generalized Pareto Distribution (GPD)

$$G_{\xi,\sigma}(w) = 1-(1 + \xi\ w/\sigma)^{-1/\xi} \quad \text{with } \xi \neq 0,\ \sigma > 0 \text{ and } w \geq 0 \qquad (4.1)$$

For a the behaviour of fat tail this corresponds to

$$P(z) \sim z^{-\lambda} * L(z) \quad \text{for } z \rightarrow \infty \text{ and a slowly varying function } L(z) \qquad (4.2)$$

These operational risk events could be fitted with $\lambda \approx 1$, i.e. without any finite mean value (for more details see: Milkau, 2022).

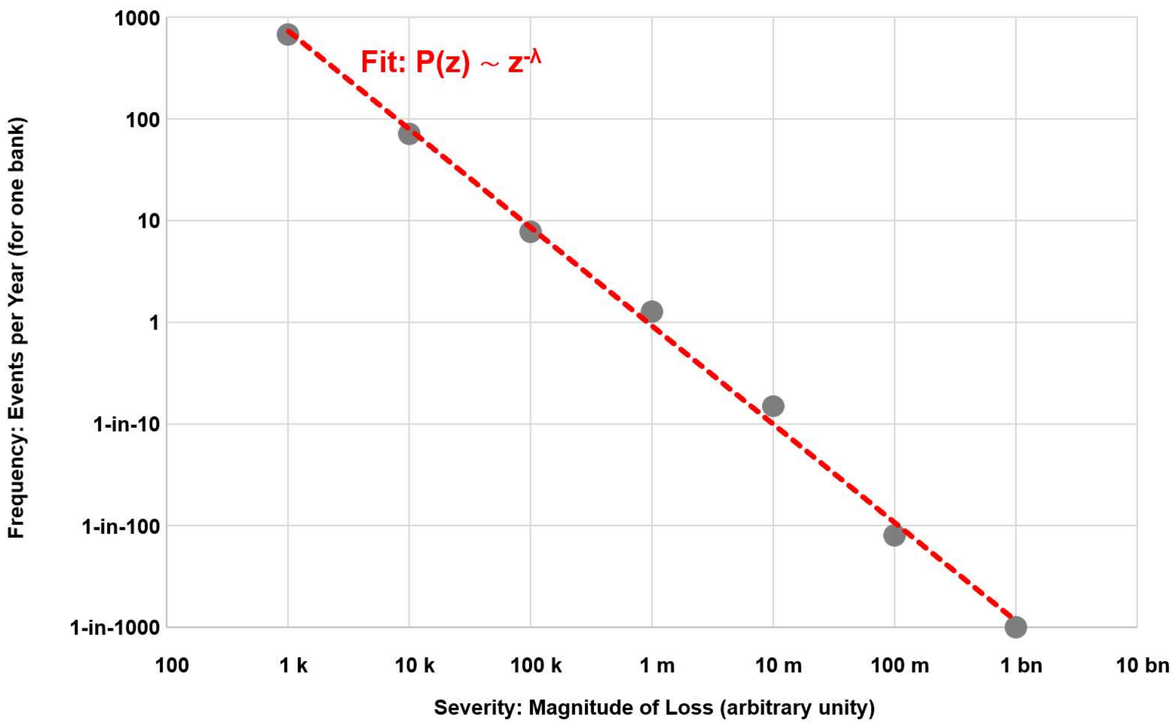

Figure 4.1: Power Law fit in a double-logarithmic presentation for an illustrative aggregated data-set of a number of banks over a decade normalized to one bank

As illustrated in Fig. 2, a Power Law fit with $\lambda \approx 1$ of a frequency-severity distribution has two consequences: the aggregated losses per magnitude (i.e. number of event times severity of losses) remains constant and the total integrated loss (from 0 to ∞) will be infinite. Respectively, each and every magnitude contributes equally – even for very rare, but very severe events.

It may be disturbing to see a probability (density) distribution with infinite mean and infinite integral. As a consequence, a number of approaches have been proposed to 'tame' this wild cat. Nonetheless, all attempts to smooth the tail and/or introduce some upper cut-off, are questionable. Of course, earthquakes – as an archetype for a power law distribution of their magnitudes – have a physical limit due to energy conservation, but this would be very much beyond every recorded or expected event. The same holds true for asteroids and their collision with earth, but already the asteroid 66 million years ago was big enough to cause the mass extinction for the dinosaurs (the Cretaceous–Paleogene extinction event - perhaps amplified by the 'Deccan Traps' and other volcanic eruptions), while the origin of the moon billions of years ago resulted from a planetoid impact of the size of today's Mars.

As mentioned, statistical methods to deal with 'extreme events' were already proposed by Benoît B. Mandelbrot in the early 1960s, and later developed to describe catastrophic events like flooding with – rather literally - '*peaks over thresholds*'. For the insurance and banking industry, Paul Embrechts et al. (1997) published their seminal book on extreme value theory (EVT), and a contemporary summary was given in Peters und Shevchenko (2015) on '*Advances in heavy tailed risk modeling*'.

According to my personal opination, the mathematical methods to deal with extreme events are not the problem. While we know quite well how to model extreme events, we suffer from a cognitive bias that we want to forget known catastrophes and develop a 'Culture of Obliviscence'. Three examples may illustrate this problem:

- Catastrophic riverine floodings in German Ahrtal were documented for 1804 and 1910, but the flood of 2021 surprised public authorities and – very unfortunately - people residing in the Ahrtal.
- Energy crisis in Germany – with a political background in times of war - were known for 1920 (coal crisis due to the reparation after World War I) and 1973 (due to the oil embargo of the Organization of Arab Petroleum

Exporting Countries in the context of the Yom Kippur War), but the natural gas crisis 2022 caused by Putin's energy war was a 'surprise'[7][8].

- The Great Financial Crisis (GFC) of 2007/2008 was unexpected, but as Carmen M. Reinhart and Kenneth S. Rogoff (2008) revealed in their work on '*This Time is Different: A Panoramic View of Eight Centuries of Financial Crises*', financial crisis displayed some regularity over centuries - and in most cases the models to calculate 'risk' for a given situation were limited to 'repeat' the near yesterdays but no the history at all.

While statistics is time-invariant, i.e. frequencies are significant but not the unit in which time is measured absolutely, our way to handle knowledge generates bias:

1. How long it takes to 'measure' rare extreme events?
2. How fast we forget – or ignore – what we experienced?
3. How fast we can learn and adapt, i.e. change either the fundamental processes or the transmission from events to damages, losses or disruption?

In financial risk management, there is a bias towards 'repeated games' and short timescales. It is assumed that the creation of the 'Value at Risk' concept (VaR) dates to Dennis Weatherstone, then CEO of J.P. Morgan, in the early 1990s, who asked for a daily report at 4.15 pm on market risk with the likely losses within one day and with 95% confidence typically, which is excluding long-term effects and fat tails beyond the 95% confidence interval. The concept assumes - implicitly – that loss events will continue in the (near) future in the same way as in the (near) past.

The Power Law might be a rather simple and phenomenological[9] fit function, but its merits result from the didactical[10] strength to cover several magnitudes of frequency and severity and to emphasise the importance of extreme events and fat tails for any decision we make today.

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[7] For decades, German politicians supported dependency on Russian gas and ensured enterprises and society that there 'is no risk' as even the former USSR in the Cold War never failed to deliver gas. Nonetheless, the price for natural gas increased already in late 2021 due to raised demand in Asia.

[8] Constanze Stelzenmüller (2022) summerized the development, which lead to this 'surprice' [quote]: 'Germany is a case study — perhaps the case study — of a Western middle power which made a strategic bet on a full embrace of interdependence and globalization in the late 20th century: it outsourced its security to the U.S., its export-led growth to China, and its energy needs to Russia.'

[9] In contrast to 'repeated games', there is no simple underlying process – like rolling dice – and different concepts have been proposed for causes of non-physical risk processes (see Milkau, 2022).

[10] As already mentioned in Chap. 2, ideas such as a black swan or a white raven might be illustrative, but distort that operational risk follows a single distribution from frequent to high-severity / low-probability events, and the coverage of recorded data depend on the time-frame.

5. Expected Utility of Tail Events

Every decision we make is made under uncertainty! If we would be certain, there is nothing to decide but simple determinism. This is no new idea, as already the Medieval sea-merchants were aware of the link between decision-making and 'risicum & periculum'. But how can very rare, but very extreme events be – literally - taken into account for decision-making?

An intensive debate about '*Discounting an uncertain future*', as Christian Gollier (2002) wrote, started in the context of climate-change: How to calculate the social costs of carbon (or costs to consume fossil fuel) or, respectively, a global carbon tax (to internalize the common costs and reduce CO_2-emissions due to adapted price)? In this context, William D. Nordhaus (2011), who received the 2018 Nobel Memorial Prize in Economic Sciences for '*integrating climate change into long-run macroeconomic analysis*', wrote in his contribution to the symposium on '*Fat Tails and the Economics of Climate Change*' [quote]:

> *Tail events are more than statistical curiosities. In some cases, they may be so important that they dominate the way we think about our options and our strategies. ... One example of how tail risk has changed economic policy is in the area of finance. In response to the meltdown of the banking system in 2007 - 2008, the theoretical approach to bank regulation has moved toward containing "systemic risk" rather than individual bank risk. Is there a general theory of economic policy concerning tail events?*

On the one side, William D. Nordhaus pointed out that collective phenomena like the Great Financial Crisis (GFC) require approaches, which extent the perspective of one decision-maker (e.g. one company or one banks) to the economic or even the socio-economic system, which will be discussed later. On the other side, he asked a rhetorical question about '*economic policy concerning tail events'* as in 2011 this debate was already going on (and is still, by the way).

It is beyond the scope of this paper to give a comprehensive summary on how do we evaluate the future? Nonetheless, I will try to give a brief synopsis and mention the different positions, as this debate goes deeply into the problem of extreme events beyond a normal distribution.

The starting point of 'intertemporal economics' is the Keynes Ramsey Rule, which (originally) describes the growth rate of consumption as a result of intertemporal optimisation of utility. As an outcome of the Ramsey model, this rule is the normative answer from the point of view of a social planer how to achieve optimal savings for a whole nation:

$$\frac{\dot{c}}{c} = g = \frac{r - \rho}{\eta} \tag{5.1}$$

with consumption c, consumption growth rate g, interest rate r (for savings), time preference or utility rate of discount ρ (for 'delayed' consumption in the future) and intertemporal elasticity of substitution η (or rate of risk aversion, i.e. readiness to delay consumption into the future).

The consumption growth rate is positive, if the (real) interest rate is larger than the time preference, as people are willing to save now and consume in future. One can rewrite this formula to:

$$r = \rho + \eta g \tag{5.2}$$

which points to the question, how much people discount the future (ρ) in equilibrium with the interest rate paid by capital markets, because people are impatient. An in-depth introduction is given by Richard S.J. Tol (2019). As he remarks, this rule assumes that the rates are known and there is no uncertainty.

If we assume that the future rate of growth is uncertain and has a normal distribution with a mean value μ and a variance σ, then the formular reads:

$$r = \rho + \eta\mu - 0.5\eta^2 \sigma^2 \tag{5.3}$$

Or in other words: If we are uncertain about the future, we should save more today (see Gollier, 2004, and Tol, 2019), which is in line with common sense.

However, this approach is a normative one, how a social planer should decide given a capital market with a risk-free interest rate. The actual time and risk preferences, i.e. what citizens prefer to do with their money, is debated and empirical studies revealed various 'non-rational' types of human behaviour.

In the context of climate change, the focus shifted from the question of preferences of saving versus consumption to the intertemporal issue of current costs (i.e. investing a part of today's welfare) versus future costs (i.e. reduction of future welfare due to climate change). In other words, how should we discount the future if there is an expected dramatic welfare loss or, vice versa, how many resources we should allocate today (e.g. costs of a carbon tax, or current negative welfare due to reduction of consumption of fossil fuel) to avoid a negative utility in the future (or damage to welfare). This question can be answered from two rather antagonistic perspectives:

- Pragmatic (positivistic) perspective how to calculate the optimum of a carbon tax with a balance between today's costs of abatement versus future costs due to damages (calculated for the scenarios with the highest probability given all available strength-of-knowledge)
- Normative perspective that under fundamental uncertainty about possible damages without any upper bound in the future, we should do everything we can today (even with highest costs) to generate even infinitesimally small amounts of welfare (or reduction of losses) to future generations

To cut a long story short, we jump to Expected Utility, which is textbook knowledge about a normative (sic!) theory of rational choice. To decide about a single 'risky' project P – let's say a Medieval sea-trade – we can assume all possible scenarios i with discrete probabilities p_i and profit (or utility) u_i and can calculate an expected utility (EU) as outcome between i=1 (no damage) and i=k+1 (maximum damage, i.e. 100% loss of invested capital):

$$EU(P) = \sum_{i=0}^{i=k+1} p_i \, u_i \qquad (5.4)$$

Switching from the perspective of individual projects (with defined time from t_o = *investment* to t_{end} = *payout*) to a societal issue such as climate change, we can interpret EU in an abstract way for a whole economy (a country or the whole world) and as a result of climate change with a continuous probability distribution of damages) on an utility U:

$$EU(Climate\ Change) = EU\ (no\ CC) - \int_{all\ damages} U(D)P(D)dD \qquad (5.4)$$

This abstract representation has to be substantiated for all concrete trajectories from t_o to a certain point in time t_x with possible measures against climate change M and discounted to the current point in time:

$$\Delta EU_{now} = \iiint_{all\ trajectories}^{t_x} U(D, M(t), t)\ P(D(M(t), t))\ P(M(t))\ dD\ dM\ dt \quad (5.4)$$

Such an approach can only be evaluated for defined (selected) scenarios. However, there are two general problems: How to integrate over time (and discount future damages to a today's baseline) and how to include measures against climate change with learning, adaption, and flexibility.

While the latter will be discussed subsequently, the first issue of integration over time refers to the question of discounting an uncertain future: Can we approximate something like $U(D,t)*P(D,t) \approx \rho(t)\ U(D)*P(D)$? Again, this approximation has two components: (i) the relation of the discounting factor and Utility $\rho(t) * U(D)$ and (ii) the behaviour of $U(D) * P(D)$:

1. For the discounting of future damage-induced utility-reduction $\rho(t) * U(D)$ this discount factor is a societal one, as it represents – e.g. for global warming – the <u>assessment of future damages by the present society</u>. But there is an underlying problem: How severe are the future damages? If we assume (nearly) infinite damages in future – such as an asteroid impact of the size, which caused the extinction of the dinosaurs 66 million years ago, the discounted damages are (nearly) infinite even for very low probabilities.
2. If we assume a behaviour of $U(D) * P(D)$ with 'fat tails' and extreme events, the integral has no finite value. In other words: any assumption of a 'catastrophic' event with 'fat tails' would represent a 'Tyranny of Catastrophic Risks' (see Buchholz and Schymura, 2010)[11].

Martin L. Weitzman (2009) was probably the first one, who discussed the effect of <u>uncertainty for the economics</u> of low-probability, high-impact catastrophes with

[11] Already Hans Jonas (1979) proposed in his book *'Das Prinzip Verantwortung'* [quote]: *'die Regierungsvorteile einer jeglichen Tyrannis, die in unserem Zusammenhang eben eine wohlwollende, wohlinformierte und von der richtigen Einsicht beseelte Tyrannis sein muss'*. I.e. he believed that for decisions about the far future with tremendous consequences (or very severe damages to avoid) the objective cannot achieved in a democratic system, and tyrannic leaders should force the society to act in the 'right' way because he regards free individuals (with bounded rationality) as 'risks' for the future.

climate change as a prototype. Although, the main conclusion of Weitzman's paper, the so-called '*Dismal Theorem*' triggered a long debate (see below), it is helpful to quote his summary in full lengths [quote, underlying by the author]:

> *With climate change as prototype example, this paper analyzes the implications of structural uncertainty for the economics of low-probability, high-impact catastrophes. Even when updated by Bayesian learning, uncertain structural parameters induce a critical "tail fattening" of posterior-predictive distributions. Such fattened tails have strong implications for situations, like climate change, where a catastrophe is theoretically possible because prior knowledge cannot place sufficiently narrow bounds on overall damages. This paper shows that the economic consequences of fat-tailed structural uncertainty (along with unsureness about high-temperature damages) can readily outweigh the effects of discounting in climate-change policy analysis.*

Unfortunately, the debate about the 'Dismal Theorem' mixed different issues:

- Question how to discount the future: see especially Christian Gollier and James K. Hammitt (2014) *'The long run discount rate controversy'* about the discussion between Martin L. Weitzman and Christian Gollier.
- Criticism of the '*Dismal Theorem*': see especially William D. Nordhaus (2011), who remarked that the assumption of a 'constant rate of relative risk aversion' (CRRA) utility function applied in the theorem results in an algebraic structure $U \sim C^{(1 - b)}$ similar to a power law.
- Maybe, the most unnoticed aspect of Weitzman's work is the confusion of a probability distribution (normal distribution or power law for probabilities) with the uncertainty or limited strength-of-knowledge. Weitzman argues that our uncertainty about climate change sensitivity requires that we have to take lowest-probability/highest-severity events into account with a strong weight. However, when we leave probabilities and enter uncertainties, we cannot apply an integration about probabilities as in equation 5.4 (and we cannot '*enhance*' probability distribution with an assumed "*tail fattening*"). In other words: the integral over all possible trajectories would be replaced by a Bayesian assumption *ex-ante* that a certain catastrophe in the future should be avoided at all (present) costs – independent from the damaging effect of such an economical re-allocation of (always limited) resources.

It is beyond the scope of this paper to enter into this philosophic discourse, but two last questions can illustrate that the use of Expected Utilities is limited:

First, if it is worth to spend all available present resources to avoid a future catastrophe – on which of the 'extreme' catastrophes should we allocation our limited resources: on an asteroid impact[12] (as 66 million years ago), on prevention of a new virus pandemic, on climate-change (with a radical stop of all emissions today and a near stillstand of our economies), or on a volcano eruption (with a possible new 'ice age' but more severe than the 'little ice ages' between 16th and 19th century)?

Second, a radical emission reduction within few years would result in a tremendous decrease of global economy, global welfare and even global food supply (with the effects of the Russian aggression on Ukraine as a very small example) – how many billions of starved people with high probability today would be 'acceptable' due to a collapse of economy to avoid an assumed future catastrophe which is extremely uncertain according to our strength-of-knowledge? This question may be unjust, but such a trade-off has to be decided beyond any Expected Utility calculation.

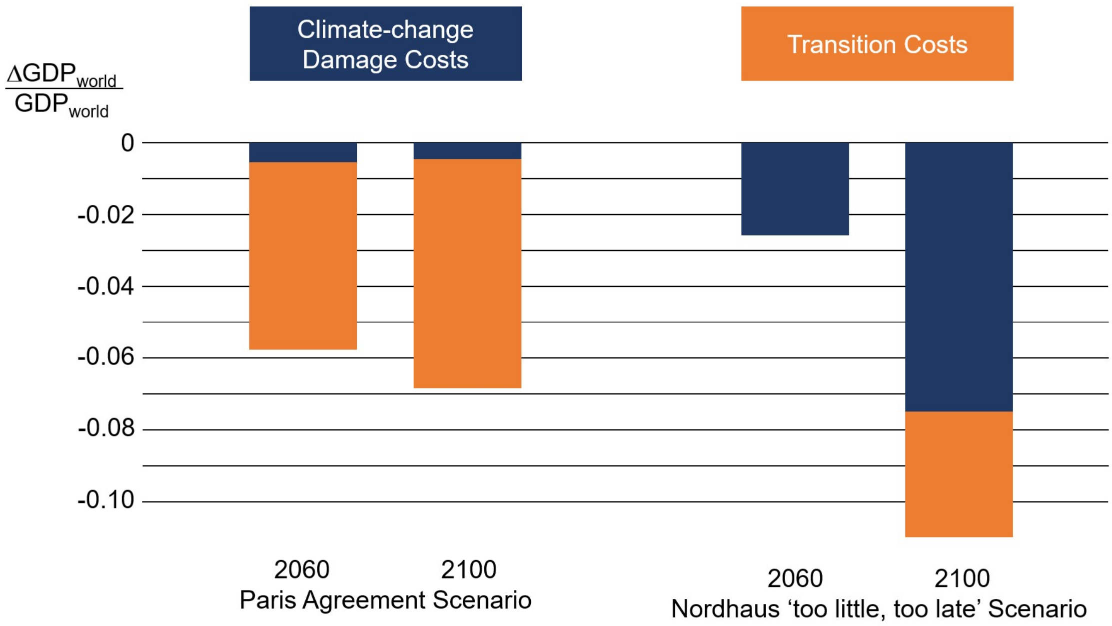

Figure 5.1: Comparison of two scenarios for the effect on global GDP due to climate-change damage costs and transition costs (i.e. measures). Data taken from ECB/ESRB (2021)

[12] With research in this direction: e.g. the DART mission of NASA with an impact on the asteroid-moon Dimorphus end of September 2022.

A pragmatic approach was presented in the report 'Climate-related risk and financial stability' prepared jointly by the European Systemic Risk Board (ESRB) Advisory Technical Committee and European Central Bank (ECB) Eurosystem Financial Stability Committee. For the discussion in this paper, Fig. 5.1 (with the data of ECB/ESRB, 2021; see also: NGFS, 2022a) reveals a number of observations.

Any calculation about climate-change does not resemble a traditional 'project' with an upfront investment and successive pay-outs - as it is assumed in Expected Utility theory - but is (i) a continuous investment over many generations with (ii) a balance of costs due to climate-change damages and (also) costs due to measures against climate-change (so-called transition 'costs'). A calculation of the reduced relative GDP[13] (=ΔGDP/GDP) caused by the combination of both types of costs enables to compare different time slots. As we can derive from the calculations for the year 2100, there should be an economic optimum between the scenario of the Paris Agreement and the Nordhaus 'too little, too late' scenario (with delayed measures compared to the Paris Scenario) with some lower transition costs compared and some higher damages to the Paris scenario. However, the year 2100 (and also 2060) is a completely arbitrary choice, which is based on the Paris Agreement with two parameters '2100' and 'max. 2 degrees', but no on any statistical significance of 2100 compared to 2095, 2110 et cetera. Nonetheless, all this calculation is based on models for both types of costs based on assumption - and current models do not include any cascading effect like the combination of a long-term drought and a following heavy monsoon in Pakistan this year, which amplified the effect of the flooding on the land nearly impermeable to rainfall.

But maybe most important, this calculation tells that there are tremendous costs - for damages and for measures against damages – over decades and over generations, which ask the question how to allocate this cost development? This intertemporal balance cannot be derived from traditional discounting approaches.

Concerning the economics of climate-change, two different perspectives exist: While Nobel laureate William D. Nordhaus, Richard S.J. Tol and Bjorn Lomborg represent an optimistic/pragmatic perspective based on a 'best-guess', the pessimistic/normative position is advocated by Sir Nicholas Stern and Nobel laureate Joseph

[13] Taking into account that the global GDP will the GDP will increase significantly between today and 210 (see e.g. Lomborg, 2020).

E. Stiglitz[14]. They shifted the debate from discounting to emphasis of 'catastrophic outcomes'[15] as exemplified in the recent publication of Stern, Stiglitz and Taylor (2022) [quote, underlying by the author]:

> *... it became broadly accepted that with temperature increases over 2 degrees Celsius there was a significant probability of extremely bad outcomes, ... One did not have to have full agreement on the utility function, the damage or abatement cost functions, discounting, or the probabilities. All one needed was convincing evidence of sufficiently high probability of very adverse or catastrophic outcomes that could be avoided at moderate costs, ...*

One can discuss whether an (annual) 7% reduction of possible global GDP are 'moderate cost'[16]. However, the idea of '*convincing evidence of … catastrophic outcomes*' similar to Niklas Luhmann's *Katastrophenschwelle* (Lumann, 1991; see Chap. 3):

> *In fact quantitative analysis always becomes irrelevant where disasters are to be feared. What is to count as a disaster is not decided on the basis of objective criteria.*

While we all agree that we have to fight global warming as good as we can (i.e. with resources allocated optimally), any debate crossing the *Katastrophenschwelle* enters the realm of subjectivity, which is beyond repeated games but also beyond any statistical science to estimate the future in a quantitative way, but which seems to require an exceptional epistemological status to put 'fear' instead of 'facts'.

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[14] Without entering a philosophical discussion about ethics, this antagonism resembles the difference elaborated by Max Weber (1919) concerning political decision-making [quote]:
'Wir müssen uns klarmachen, dass alles ethisch orientierte Handeln unter zwei voneinander grundverschiedenen, unaustragbar gegensätzlichen Maximen stehen kann: es kann „gesinnungsethisch" oder „verantwortungsethisch" orientiert sein.`

[15] A similar worst-case perspective was elaborated in Kemp, Luke et al. (2022) 'Climate Endgame: Exploring catastrophic climate change scenarios' [quote]:
'Yet there are ample reasons to suspect that climate change could result in a global catastrophe.'

[16] Alexandra Jour-Schroeder, Deputy Director General of the Commission´s Directorate-General for Financial Stability, Financial Services and Capital Markets Union, gave an indication in an interview when asked how the European Commission wants to provide the enormous amounts of funds that are necessary to finance the transition to a sustainable economy [quote, Jour-Schroeder, 2022]:
'Let´s be honest: this is a rather daunting task. Europe will need an estimated EUR 350 billion in additional investment per year over this decade to meet its 2030 emissions-reduction target in energy systems alone, alongside the EUR 130 billion it will need for other environmental goals.' However, this amount may be a lower bound, as the European Union spent about EUR 300 billion on the energy crisis between March and Sep. 2022 to soften the price shock for citizens and economy.

6. Learning, Adaption, and Innovation

Thomas Robert Malthus (1766 to 1834) and his ‘Malthusian catastrophe’ was perhaps a first example of a ‘statistical’ prediction based on a perpetuation of the past to the future and the beginning of a categorical pessimism. He assumed an exponentially growing population versus constant agricultural resources, which would lead to the trap of food supply. However, his first mistake was to ignore that an agricultural innovation - the introduction of the potato from America in the 16th century - triggered the population development he had critically considered. From a modern point of *ex-post* view, he assumed the technology of 1800 to be frozen, i.e. without tractors, fertilizers and current ‘precision farming’. This approach can be described as:

- a ‘steady state’ – i.e. a future like the past – i.e. ‘repeated game’.

Similar approaches with (implicit) assumptions of a ‘steady state’ continued, and the most prominent may be the predictions of the Club of Rome of 1972 on the ‘*limits of growth*’. Nonetheless, all predeterminate scenarios of the Club of Rome – and especially the noticeably ‘*peak oil*’ with limited resources in fossil oil - have proven to be wrong (e.g. due to fracking technology). The catastrophes seen by Club of Rome never materialized. The principal fault – beside a naïve believe in an very simple simulation models aligned to the computer capacity of the 1970s – has always been to extrapolate the past to future scenarios with fixed conditions[17], but without human ingenuity in science and technology and without creative innovations by ‘risk-taking’ entrepreneurs in a free market economy.

This legacy continued from Thomas Robert Malthus via the Club of Rome to Sir Nicholas Stern and Joseph E. Stiglitz. As a strange manifestation of the confirmation bias, we seek to find arguments for what we experienced (or believe to know) but ignore the – positive – opportunities of an unknown future, which can be sized by human ingenuity in an open society and free market economy.

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[17] The recent publication of the Club of Rome (2022) 'Earth for All: A Survival Guide for Humanity' repeats this principal fault and states explicitly [quote]: *'The data from the models are not set predictions for the future but likely scenarios based on current data and science available today. This applies to all models that calculate, assess, or estimate climate change, demographics, or anything else into the distant future*.' However, the approach is strangely consistent as [quote]: *'That is why the authors also argue for the creation of a novel financial innovation, the Citizen’s Fund, to tackle inequality, ... The fund would distribute the wealth of the global commons to all people as a Universal Basic Dividend*.' While the model is – again - a simple continuation of the past into the future, the call for a 'novel financial innovation' to 'plan' a distribution of wealth resembles old visions failed long ago (at lease with the collapse of planned economies in 1989).

It is true that not much changes from the 'The Bankers of Puteoli' of the 1st century (Jones, 2006) to merchant banks of the early modern period[18]: banking and risk transfer was linked to trading (or financing of sovereigns as done by the Fugger family, but hopefully collateralized by commercial rights such as mining or trading rights). The largest part of population – except aristocracy and some economic elite like large merchant houses – was fully dependent on 'the will of gods' (either natural forces or command of rulers) during Medieval age as in the centuries of human history before.

But the Great Enlightenment started a plethora of innovations so that the GDP/capita (inflation adjusted) of industrial nations increased by a factor of 20 to 40 between 1800 and 2000 (see: Rosling, 2018). It is important to make a warning as neither this positive development (of a free market economy in an open society although interrupted by wars and some periods of planned economy) can be taken for granted, nor can we exclude a fallback to the illusion of planned economies.

Nonetheless, the development of the market economy during the last 200 years proved that an open society – in contrast to an *ex-ante* planned economy – will be able to employ learning, adaption, and innovation in a step-by-step process driven by market economy. In this context 'learning' is not restricted to typical try-and-error process based on existing knowledge. We have the human ability to lean new concepts, develop innovative technologies and make vision come true, which can be illustrated by John F. Kennedy's famous speech on 12.9.1962 *'We choose to go to the Moon in this decade* ...'.

[18] It is beyond the scope of this paper to discuss the development of deposit-taking by banks and introduction as a fractional reserve system (with maturity transfer between short-time savings and long-term loans; see especially the Diamond–Dybvig model for *'bank runs, deposit insurance, and liquidity*' by Diamond and Dybvig, 1983). However, some historical development is worth to note: Since 'The Bankers of Puteoli' there had been a separation between banking (with short-term financing based on the bankers' equity) and direct investing in a company or trade project. Until the later Middle Ages, Christian merchants and bankers were not allowed to take interest, but at the end of this time Jewish money-lenders lost their privileged position. In parallel, the inflow of money and precious metals from South/East Asia and the Americas triggered a demand for deposit-taking institutions. But money in vaults of banks could have been a 'risky' business, as documented in the case of confiscation of precious metals from vaults of banks in Seville by the notorious penniless Charles V (Carlos V) in 1545 (see: Caranda, 1987 and Huerto de Soto, 1996). Consequently, banks started with a – disputed – maturity transfer of interest-bearing deposits versus loans to commercial projects. This has to be distinguished from early public deposit banks such as the Bank of Amsterdam and the Bank of Hamburg, which took deposits in form of coins and precious metals and issued 'credit' on these accounts (see: Schnabel and Shin, 2018). Only after the Great Enlightenment, ordinary citizens developed a demand for deposits The first savings banks started in Hamburg in 1778 as '*Ersparungsclasse*' and first co-operative banks began in 1843 with the *'Öhringer Privatspar- und Leihkasse*'.

In this sense, adaption – together with learning and innovation - is the human way to tackle new challenges, for which no blueprints from the past exists: whether sending a man to the moon (and hopefully women in the future, too), developing a mRNA vaccine against the Covid-19 virus, or future 'adaptive' water management systems (see: Pahl-Wostl, 2022), which will be required also for a country like Germany being considered as water-rich for a long time.

This is a fundamental difference to 'repeated games', which never change and are completely predictable in a statistical sense. Of course, our human society is far from being perfect and will – without doubt – make many wrong turns. However, the 'non-planned' process of the market with its continuous search for 'better' solutions – without the guaranty to obtain global optimization instead of local improvements – is the best tool we have at hand to find our way into the future, if and only if we avoid pretending to know the solution *ex-ante*.

Vice versa, statistics can help to qualify different open directions, but cannot estimate a far future of socio-economic systems. Only a process of constant careful monitoring, self-critical evaluation, learning from failures[19], and innovative adoption will avoid the traps of 'planned solutions'.

One final remark concerning 'adaption' is worth to be made at the end of this chapter, as 'adaption' is also a concept in the science of complexity. As W. Brian Arthur (2015) wrote [quote]: '*Complexity is not a theory but a movement in the sciences that studies how the interacting elements in a system create overall patterns, and how these overall patterns in turn cause interacting elements to change or adapt. … Complexity is about formation - the formation of structures - and how this formation affects the objects causing it*.' Simple implementations are so-called 'cellular automatons' with the well-known example of John Horton Conway's *'Game of Life*' (Gardner, 1970) based on the theoretical work of John von Neumann, Stanisław Marcin Ulam and Arthur. W. Burks.

[19] However, the idea of 'learning from failures' can be read in many mission statements, but is hard to achieve and strongly depends on incentive structures (see e.g. Dahl and Werr, 2022, but also Chap. 8 in this paper).

More advanced applications are 'Complex Adaptive Systems' (CAS) – typically the biological evolution or computer simulations – in which (i) many agents (ii) interact or exchange signals and can (iii) form modular sub-groups to (iv) adapt to a changing environment. Great introductions are the contributions by Murray Gell-Mann (1994) and John H. Holland (2006).

An important difference between CAS and 'non-adaptive' complex systems are the requirements (iii) and (iv). There is a multitude of complex systems in physics – see especially the great summary of Nobel laureate Giorgio Parisi (2006) about so-called 'spin glasses' with a co-existence of many equilibrium states and impossibility to predict the most stable state ex-ante – which follow (i) and (ii).

The step to CAS comes with modular differentiation and responsive adaptivity[20]. These 'Complex Adaptive Systems' can include 'evolutionary' developments – e.g. changes in the coded rules by statistical recombination or exchange of 'statements' by chance. Nonetheless, they depend conceptionally on trial-and-error, which has to be distinguished from rational insight, scientific understanding, human innovation, and active cooperation. While CAS requires 'interaction' as condition (ii), this interaction can be a pure exchange of forces (e.g. magnetic forces in a spin glass or – even simpler – in the interaction of elementary magnets in a two-dimensional Ising Model).

To achieve 'active' cooperation an agent has to have an ability to evaluate its benefit from an interaction according to a payoff function. Game theoretical approaches can model simple types of cooperation such as the well-known Prisoner's Dilemma (see especially the book by Nowak and Coakley, 2013, for on overview), but include the assumption of some 'repeated game' with given rules - and given payoff function.

[20] It is remarkable that even collective single-cell organisms like the mycetozoan branch of the amoebozoa group of organisms are able to show [quote]: *'Pronounced cell differentiation processes and even multicellular development in response to environmental conditions are found in the mycetozoan branch of the amoebozoa group of organisms'* with *'Transcriptome reprogramming during developmental switching in Physarum polycephalum involves extensive remodeling of intracellular signaling networks'* (see: Glöckner and Marwan, 2017).

7. Operational Resilience and the Future-II

After the discussion of extreme (but still predictable) events, we leave the realm of the traditional calculus of probability and enter into the counterfactual worlds that

‘*could have been*’ (i.e. conditional past)

in the words of Pearl (2018). We will even go a step further and ask for things that

‘*potentially will have been’* (i.e. future perfect or future-II).

In other words, we enter into a realm of potential ‘risky’ events - regardless of our measures to avoid / reduce / mitigate risk in a traditional sense.

There is no commonly accepted definition of ‘*resilience*’[21,22], but two definitions from different fields may provide some preliminary explanation:

- According to the Basel committee (BCBS, 2021), operational resilience is the ‘*ability of a bank to deliver critical operations through disruption’*.
- According to NATO (2021) resilience means ‘… *to resist and recover from a major shock such as a natural disaster, failure of critical infrastructure, or a hybrid or armed attack*’.

Consequently, we will understand **operational resilience** as an ability to

***recover from disruptions and restore critical operations*.**

In this sense, ‘resilience’ is an attempt to look ‘behind’ the veil of the future and assume a scenario, in which ***things have gone wrong*** – despite all our attempts in risk management to avoid, reduce, mitigate, or even accept risk events. Of course, we allocate a lot of resources to circumvent an extreme risk event or disruptions.

[21] In the context of this paper, ‘resilience’ should not be regarded from a psychological perspective as often used in the German terminology of “Resilienz”.

[22] Unfortunately. The term ‘resilience’ is also used in popular books such as Jeremy Rifkin’s *'The Age of Resilience: Reimagining Existence on a Rewilding Earth*' (to be published 1.11.2022). He applies a quite esoteric perspective with a manipulative use of terminology, which is illustrated in the information of the publisher (St. Martin's Press, 2022) [quote]: ‘*The Age of Progress, once considered sacrosanct, is on a deathwatch while a powerful new narrative, the Age of Resilience, is ascending. ... The autonomous self of the Age of Progress is giving way to the ecological self of the Age of Resilience. The now worn scientific method that underwrote the Age of Progress is also falling by the wayside, making room for a new approach to science called Complex Adaptive Systems modeling. Likewise, detached reason is losing cachet while empathy and biophilia become the norm. ... At a moment when the human family is deeply despairing of the future, Rifkin gives us a window into a promising new world and a radically different future that can bring us back into nature’s fold, giving life a second chance to flourish on Earth*.’ This perspective has nothing in common with the concept of ‘*operational resilience*’ applies in this paper.

Nonetheless, ‘resilience’ requests us to accept that all our thinking and measures might have been wrong. Or in other words, how can we restore operations after some disruption, which contradicts all out best plans and preparations.

In extension of the concept of ‘risk’ in Chap. 2, different steps toward operational resilience can be derived.

1. Robustness

$$Robustness = \{P_i,\ \text{‘}1\text{-}C_i\text{’} \mid E_i;\ SoK \approx 1\} \quad (7.1)$$

For a certain ‘risky’ event E_i with a probability P_i and a specific consequence C_i, while robustness means that given E_i happened (i.e.: | E_i), the ‘risky’ and undesired consequence (‘1-C_i’) can be avoided.

2. Specific Resilience

$$Resilience = \{U,\ \text{‘}1\text{-}C_i\text{’} \mid \forall S;\ SoK < 1\} \quad (7.2)$$

For all possible scenarios S (∀S) with a specific consequence C_i, while resilience means that given any scenario happened (i.e.: |∀S) taking into account the uncertainty U due out limited strength-of-knowledge the ‘risky’ and undesired consequence (‘1-C_i’) can be avoided.

3. Operational Resilience

$$Op.\ Resilience = \{Operations\ (\forall\ i;\ \text{‘}1\text{-}C_i\text{’}) \mid \forall S;\ SoK << 1\} \quad (7.3)$$

For all possible scenarios S (∀S) and all negative consequence (∀ i; C_i,), operational resilience means that Operations can be restored given any scenario (i.e.: |∀S), while our strength-of-knowledge is very limited.

4. Resilience of a Market Economy

$$Market\ Economy = \{Innovations\ (price\ signals) \mid \forall C_i;\ SoK \approx 0\} \quad (7.4)$$

For all possible negative consequence (∀ i; C_i,), the price signals in a market economy enable a re-allocation of resources based on the ‘*random*’ search processes in the market (from production capacity and supply to research & development), even if some operations might be disrupted, which cannot be predicted due to missing strength-of-knowledge.

Although this seems to be a very formalistic approach, the differences what 'disruption' means, can be exemplified:

1. A certain event causing a defined failure with a duplicated back-up (e.g. two hard-disks with hot swap redundancy).
2. A failure of one specific component with many possible root causes and a back-up solution, which is completely independent[23] (e.g. other type of component, other provider, other software et cetera).
3. A failure of any component - in a power grid for example - with the assumption that only one event happens at a time and the maxim of N → N-1 (i.e. one power plant, one network connection[24], or one supplier can fail without severe disruptions – although some temporarily reorganisation could be required).
4. A disruption of some (critical) operation, which can be substituted although not planned before (e.g. the Covid-19 mRNA vaccine development, production and distribution).
5. The challenge of 'Compounding and Cascading Events' (see: National Academies, 2022) which can be described as [quote]: *'Today, there is a new normal - most disasters do not occur as isolated events and instead seem to pile on one another, disaster after disaster, often unleashing new devastation on a community before it has had a chance to recover from the prior disaster. ... Furthermore, acute events can be compounded by chronic deteriorating conditions, such as an acute, intense rain event causing mudslides and flash flooding in an area that had been experiencing extreme drought. ... Recovery requires more than getting back to normal, especially when what is considered normal may be a major contributor to a community's vulnerability to cascading disasters*.'

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[23] One example can be critical components in computer networks - like routers and switches - which can be implemented redundantly to back-up the failure of one device. While this redundancy can cover material damages or fatigue on one specific component, identical devices (with identical hardware and identical software) are once again a Single-Point-of-Failure, if e.g. an updated software version has a bug - as all devices will implement this bug identically.

[24] The N→N-1 maxim is an active approach assuming that a component such as a network can fail or can be attacked although measures against failures or attacks are implemented. This has to be distinguished from the – wrong – assumption that a '*security by obscurity*' could be achieved, i.e. by hiding information about the structure of a network et cetera.

The less we can anticipate possible disruptions of critical operation due to our limited strength-of-knowledge, the more we leave the known land of 'repeated games' and enter into a realm of unpredictable[25].

> **However, we have to accept that the unpredictable will have happened once in the future.**

This is no contradiction, but key to operational resilience. In parallel, we cannot 'plan' how to restore operations after an unpredictable disruption, as we simply cannot predict it.

As the hierarchy of formulas 7.1 to 7.4 indicate, 'unpredictability' cannot be solved with traditional redundancy, but with an extended scope, how operational resilience can be achieved by a suitable design of the environment like a network (power grid) or a market (market economy).

The idea of a '*Resilient Society*' was articulated by Markus K. Brunnermeier (2021) in his same-titled book. He analyses situations such as the Covid-19 pandemic and readers are referred to his intriguing book for details. While being societal solutions, his ideae can be implemented on the level of market economy in a more 'technical' sense. If one company will go into default, other ones will see a chance for profit and fill this gap in short time. The search process of the market economy allows to solve unpredictable problems, whereas any central planning would suffer from a disruption, as a social planner always assumes some kind of '*repeated game*', which can be calculated *ex-ante* in full detail.

However, we should notice that market-based resilience and systemic risk are two sides of the same coin. The more linked a network or an economy is, the greater a systemic risk is that one problem will cause contagion of parts or even the whole network. No formal solution for this challenge exists today, and a more pragmatic approach is a cascade of operational resilience at entity level (which can absorb contagion at least to a high degree) and flexibility of a market economy (to fill gaps if one entity fails).

[25] See also the strategy paper 'Resilienz der Telekommunikationsnetze' of German Bundesnetzagentur (2022)

A well-known example is the regulation of economic capital for banks and financial services companies, which provides a resilience for unexpected ‘risks’ but let the market operate as independent as possible. A basis of economic capital has another advantage as such a general provision avoids the trap to assume that known systemic risk events such as the Great Financial Crisis will happen in the same way as we experienced once and could be predicted. Although Reinhart and Rogoff (2008) revealed that financial crisis are not rare and share some pattern, they are no ‘repeated games’. Consequently, we cannot predict the next crisis (like ‘*predicted maintenance*’ in engineering, where early warning signals – e.g. a changed noise frequency spectrum generated by rotating devices – can be used to exchange parts before the fail), but we enable banks and the financial system to absorb stress up to a certain level and keep critical operation running.

8. Intertemporal Decisions and Incentives

The regulation of economic capital – for more stability of the financial systems against systemic risk events – exemplifies that measures against the unpredictable come with costs. The GFC revealed that a naïve approach with minimum capital (and assumption of non-correlated markets such as U.S. mortgages) might be cheaper with less allocated economic capital for a bank but cannot sustain in times of a systemic risk.

On a societal level, a parliament, a banking supervisor, or subordinated agency can design an appropriate framework to achieve long-term financial stability and a (more) resilient financial system. Although there are no numbers on a granular level to calculate the cost of economic capital versus prevented financial losses at a crisis, this can be treated qualitatively either as an intertemporal zero-sum game or as a (very) long-term investment in future social benefit. As costs (now and ongoing) have to be balanced against avoidance of costs (in the future), this social agreement belongs to the type of intertemporal distribution of freedom: there is an intervention in freedom rights today (with the obligation for banks to hold economic capital) to care for a crisis with an impact on freedom rights in the future[26].

This point of view changes when we examine individuals making decision with intertemporal consequences. The challenge can be stylized in the following way:

> **A decision has to be made today, which will result in costs now and perhaps ongoing, to build an operational resilience for some disruption never seen before, assumably very rare (however it could happen tomorrow) and not predictable due to our missing strength-of-knowledge.**
> **But if it will have happened, operations will fail and has to be restored.**

Three perspectives can be analysed: Can a decision-maker understand the challenge and act reasonable, although it seems contractionary? How is the decision-maker – as an agent of a company or organisation (i.e. a principal) – incentivized to made a reasonable decision? Which objectives (or objective functions) do the principal want to achieve?

[26] In general, this can result in a complicated debate as already indicated for climate-change and a potential global carbon tax to balance the social costs of carbon.

Before we try to answer these questions from a normative and a pragmatic perspective, it is worth to note that this challenge can be regarded as a variant of the so-called St. Petersburg Paradox or St. Petersburg Game (described by Nicolas Bernoulli in 1713; see: Pulskamp, 2013), which is an 'infinite' game offered by a casino with an infinite expected value, i.e. chance to win an infinite amount of money, if one plays the game for an infinite time[27]. In the case of operational resilience, the 'win' is an avoided an 'infinite' disruption. The question in the St. Petersburg Game is, how much should a rational gambler invest, when the expected value of the win is infinite - given (sic!) one can invest infinite time to gamble until the very end. A very intriguing introduction was given by Paul A. Samuelson (1977), including different ways to solve – or circumvent – the paradox. One way was elaborated earlier by Paul A. Samuelson (1960) that no casino on earth (i) will be able to offer an infinity win and, consequently, (ii) the number of rounds will be limited (e.g. until night ends). Another 'solution' is a psychological one, as nobody would make a very high stake now to receive a tremendous win in the far future – or in a worst case long after the death of the gambler. This paradox unveils that even for deterministic games[28], possible payoffs in the future collide with practical issue and psychological limits.

The debate about decision-making under uncertainty is as old as the calculus of probability, and already Nicolas Bernoulli mentioned it in the context of the St. Petersburg Game [quote, according to Pulskamp, 2013; underlying by the author]:

> *From all this I conclude that the just value of a certain expectation is not always the average that one finds by dividing by the sum of all the possible cases the sum of the products of each expectation by the number of the case which gives it; that which is against our fundamental rule. The reason for this is that the cases which have a very small probability must be neglected and counted for nulls, although they can give a very great expectation.*

[27] The casino offers a single player game in which a fair coin is tossed at each stage. The initial stake is doubled every round. The first-time tails appears, the game ends and the player wins whatever is in the pot. For a stake of x the player wins 2x if tails appears on the first toss, 4x if heads on the first toss and tails on the second, i.e. a series (n-1) heads + one last tail let the player $2^n x$.

[28] It is beyond the scope of this paper to enter into the discussion, how rational behaviour can be defined and how rational gamblers should act. John von Neumann (1928) '*Zur Theorie der Gesellschaftsspiele*' and John von Neumann and Oskar Morgenstern (1953) '*Theory of Games and Economic Behavior*' are - still - wonderful starting points to enter into this topic.

A contemporary critique to rational decision-making is the well-known ‘prospectus theory’ of Daniel Kahneman and Amos Tversky (1979) [quote, underlying by the author]:

> *This paper presents a critique of expected utility theory as a descriptive model of decision making under risk, and develops an alternative model, called prospect theory. Choices among risky prospects exhibit several pervasive effects that are inconsistent with the basic tenets of utility theory. In particular, people underweight outcomes that are merely probable in comparison with outcomes that are obtained with certainty. This tendency, called the certainty effect, contributes to risk aversion in choices involving sure gains and to risk seeking in choices involving sure losses.*

An alternative concept is ‘heuristic decision-making’, which was developed by Shabnam Mousavi and Gerd Gigerenzer (2014) [quote, underlying by the author]:

> *In making sense of uncertainty, the mathematics of probability that is used for risk calculations may lose relevance. Fast-and-frugal heuristics, on the other hand, provide robust strategies that can perform well under uncertainty. The present paper describes the structure and nature of such heuristics and provides conditions under which each class of heuristics performs successfully. Dealing with uncertainty requires knowledge but not necessarily an exhaustive use of information. In many business situations, effective heuristic decision-making deliberately ignores information and hence uses fewer resources. In an uncertain world, less often proves to be more.*

While these three approaches highlight different aspects of ‘decision-making under uncertainty’, they all describe derivations form ‘statistical rationality’, because human beings show cognitive problem to handle small probabilities (or very rare events) and fundamental uncertainty (beyond the simple concept of ‘repeated games’). This problem is even more pronounced if ‘we’ (either an individual decision-maker, an organisation or even a society) never faced one rare event in the timeframe of our experiences. Or, if ‘we’ developed a ‘Culture of Obliviscence’ and for example settle in risky areas although historical disasters are recorded and documented (see Chap. 2 concerning the catastrophic riverine flooding in the Ahrtal).

A rather modern version of the St. Petersburg Paradox is the ideology of the so-called '*long-termism' (aka 'effective altruism')*, a term coined by William David MacAskill (né Crouch) in 2019 and defined as [quote, MacAskill, 2019]:

Longtermism is the view that positively influencing the long-term future is a key moral priority of our time.

As more extended description is provided by Greaves and MacAskill (2021) with the quote:

The potential future of civilisation is vast. Once we appreciate this, it becomes plausible that impact on the far future is the most important feature of our actions today. ... For example, even if there are 'only' 10^{14} lives to come (as on our restricted estimate), a reduction in near-term risk of extinction by one millionth of one percentage point would be equivalent in value to a million lives saved; on our main estimate of 10^{24} expected future lives, this becomes ten quadrillion (10^{16}) lives saved.

Nonetheless, this contemporary excitement about '*Longtermism'* is resuming a misunderstanding about statistics: If one aggregates – in an extreme utility theory fashion – either all fictional future damages or future benefits, the result is to allocate all current resources to the (potential) future and nothing to (actual) current situation (otherwise the future is discounted in a way that all 'long-term' damages or benefits can be ignored).

The benchmark of (extreme) utility leads to shift of paradigm who holds responsibility, as Gilles Saint-Paul (2011) pointed out. On the one side, decision-makers would be made responsible for mere correlations with fictitious future impact on other people. One the other side, individual responsibility for our decisions would be re-aligned to a vague concept of general 'social well-being', in which an anonymous 'social planner' takes over decision-making in the name of paternalism defined by an (unbound) optimization of social utility.

Of course, any altruistic human being – or a SME family enterprises – will align current decisions in a way to preserve existing assets – societal, environmental, or economical - for future generation. But an unlimited devotion to unborn future generations and support of a 'tyranny of the future' would be an endless St. Petersburg Game.

In particular, any aggregation of (not discountable) fatalities over the whole future of humanity on Earth would rationalize to allocate every resource today on an uncertain future and on potential generation, which will or will not be born many thousand years in the future.

Box 2: So-called 'Longtermism' as modern version of the St. Petersburg paradox

Unfortunately, this three concepts do not fully cover the situation in scope of this paper. They all assume a situation, in which 'we' have to decide – as a gambler, an investor, a judge et cetera. But they do not cover the meta-level of scenarios, in which 'we' have to decide whether 'we' should decide at all. Additionally, statistical estimations do not include a subjective 'cut-off threshold' due to personal timeframes, in which decision-making takes place: from a current project as a 'undertaking for a certain time' to the mandate of a corporate executive. All these scenarios have one question in common:

Is there an incentive for the decision-maker to make a decision?

This issue is an antagonist to the textbook 'principal–agent problem' because it does not refer to a conflict in interests and priorities between the (executing) agent and the (commanding) principal but to a missing motivation for the agent concerning inter-temporal decisions.

As operational resilience is '*tangible future-II*', it is always additional to standard risk management. In other words, a company already spends money on risk management measures to prevent losses due to failed objectives, which are estimated by statistical risk management methods. Additionally, operational resilience assumes that – against all costly measures – a disruption will have happened and more money is required to implement procedures to restore operations. A decision-maker has to justify additional costs – in contradiction to textbook economies-of-scale to achieve cost reduction due to aggregation on a centralized production facility - but can only refer to uncertainty.

As Nicolas Bernoulli (see above) and Niklas Luhmann (1991) discussed from different starting points, 'we' are focussed on normal distributions and probabilities of medium-range frequency but ignore the highly improbable especially if the corresponding frequencies are far beyond human timeframes – although 'rare' events can happen tomorrow statistically. If the timeframes are connected to missing incentives (money, reputation, group behaviour, corporate culture et cetera), 'we' can always find a good justification to avoid decision-making with spending money on a 'future-II'. Vice versa, an extreme utilitarian perspective, that only future counts (see Box 2), can retract decision-makers from their responsibility to act here and now.

9. Repeated Games and Adaptive Systems

Human beings with a limited lifetime and bounded rationality feel very comfort in situations with ‘repeated games’ or a ‘plannable’ steady-state economies. We can find this comfortable calculability from Thomas Robert Malthus (with his Malthusian trap) to all planned economies, the lament of Theodor W. Adorno (in a radio discussion with Ernst Bloch, 1964), the naïve predictions of the Club of Rome and contemporary activist against capitalism and/or market economy. Today, there is a tremendous fear of any future uncertainty beyond a ‘beneficial’ social planner, while ‘*Rome was a culture that look danger in the eye*’ as Mary Beard (2011) pointed out.

Concerning a long-term perspective on risk or disruptions with ‘rare’ low-probability / high-severity events, an assumption of a ‘steady state’ economy is incorrect for industrial economies since the Great Enlightenment starting from 1800. Still – unfortunately – the poorest countries with typically subsistence economy like Niger, Somalia, Kongo, Mali, and Chad have the highest birth rates between 6,8 and 5.7, but the lowest social welfare (health, nutrition, education, women rights et cetera), and people are living from hand to mouth. Quite the opposite, industrial nations increased public welfare (as measured by the proxy of GDP) between 1800 and 2020 by a factor of 20 to 40 (Rosling, 2018). Of course, GDP is only a simplified proxy but correlated with other factors such as health, nutrition, education, women rights, but also with (i) decrease of population for the first time in history and (ii) the capability to reduce pollution, optimize energy consumption[29] and even invest in a transition to a zero-carbon economy. In an unsophisticated way, pre-industrial societies suffer from a steady state trap with an immanent daily danger for everybody, whereas market economies vanquish this exposure to external forces and enabled individuals to make economic decision – however always under uncertainty.

In other words, a long-term perspective on risk and resilience requires some freedom from the ‘mercy of gods’, and this economic development enables societies to cast off the shackles of a ‘steady state’ destiny. This observation is important, as it points to a new aspect: the connection of risk and economic context.

[29] As an example, the German GDP increased by 24% between 2005 and 2019, while CO_2 emission decreased by 21% (Krohn and Pennekamp, 2022). This is not sufficient to stop global warming, but Germany, the European Union, UK, the USA and similar industrial nations are the only example for emission reduction at all.

As shown in formula 2.5, the calculation of a 'risk' in a Bayesian interpretation with a (subjective) condition an assumption A ('given A') can depend on an external control parameter like a growing population in a region predisposed to flooding:

$$R(x)_S = \{E, L, P_S \mid A; SoK_A=1; x\} \qquad \text{(again 2.5)}$$

Similarly, a long-term 'risk' in dependence of a given, but changing context can be defined:

$$R(t)_{long\text{-}term} = \{E, O \mid Context(t), U(SoK<1)\} \qquad (9.1)$$

The ability to allocate resources (people, money, time et cetera) to build dikes depending on the public welfare in a growing economy is an equivalent example. A country like the Netherlands was never 'steady state' but a dynamically evolving economy with the ability to learn, adopt and innovate – and to build dikes, which would not have been impossible in the early 1800s.

As the concept of 'risk' is closely related to sea trade, one can follow Mediterranean sea-trade through the centuries to analyze the change of context over time:

- A first milestone is the trade city of Amalfi (near to Puteoli – sic!), which achieved independence from the Byzantium end of the 9th century, but continued trade in the South-Eastern Mediterranean and developed a legal framework[30] of risk-sharing as 'colleganza' on the basis of former Roman law.
- Venice established dominance in the eastern Mediterranean based on military strength – first supporting Byzantium and later as enemy – from late 11th century until the trade routes shifted to Western Europe and then to over-sea trade.
- In the Western Mediterranean, city republics like Genoa, Pisa, Marseilles, or Toulouse increased sea-trade, established risk-sharing as 'commenda', but also connected sea and land trade (especially with the Champagne fairs[31] in Northeastern France in the 12th and 13th century).

[30] Although Amalfi lost its importance to Venice, the code of maritime laws compiled in the 12th century in Amalfi, the 'Tabula Amalfitana', was applies as standard mercantile code in the Mediterranean until the 15th century.
[31] The Champagne fairs were largely self-regulated through the development of a 'Lex Mercatoria' concerning trade issues.

- Later on, the trade patters shifted in Northern direction and to merchant cities like Antwerp and Amsterdam. In parallel, international trade started with Africa, Asia, and the Americas, which resulted in the development of new company types such as the Dutch East India Company (VOC) with the fist 'initial public offering' ever in 1602.

While 'trade' was always the same concept, the 'risk' connected with every enterprise was determined by changing aspects such as regional focus, political situation, legal framework, and specific risks from pirate attacks to war between sovereigns. Vice versa, merchants adopted to these changing aspects with new routes, new forms of organization (including merchant ship convoys escorted by war galleys), new technologies (ship types) and new legal developments never seen before.

However, trade never was a 'repeated game' – and traders like the merchants of Venice, who believed that their dominance would continue forever independent of shifts in global trade patterns, had to realize that a different setting contradicted their methods to manage daily operational risk, because of a (long-term) strategic risk due to the dependence on the context.

Other traders benefited from this situation, because they did not believe in trade as an endless 'repeated game' but were able to adapt to a dynamical development of the world. While they still had to manage their 'operational risk' of single decisions, they did not extrapolate their risk at a certain point in time and for the duration[32] of an enterprise $R(t_0, \Delta t)$ to a far future. They understood that changing circumstances (politically, technologically and social) had to be monitored and decisions had to be adapted step-by-step over time with a context-dependent risk $R(t) = R(C(t))$. Vice versa, they provided the proof that human beings can invent, innovate, and derive new solution, where no men gone before.

This optimism concerning human ingenuity and ability to innovate might be naïve, but the development since the Great Enlightenment proved that – at least – there is a probability to overcome Malthusian traps in principle, if we avoid being ridden by a *German Angst* of positive developments in an unknown future.

[32] The issue that 'risk' can be defined for an interval from t_1 to t_2 is discussed by Tarje Aven (2021).

10. Risk, Probability, and Physical Processes

The world around us is fundamentally a world of many-body systems. Gas or fluids behave according to the rules of statistical mechanics. Planets move deterministically according to the rules of gravity but cannot be predicted over long terms due to the sensitive dependence on tiny changes in initial condition. Measurements have to deal with (external) noise due to the impact of the environment. And biological systems such as predator–prey relations, can be modelled by a pair of first-order nonlinear differential equations, but with sensitivity on control parameters with can force them to behave in a ‘chaotic’ way.

Four examples are shown in Fig. 10.1 to illustrate different types of natural behaviour: a) the random walk of a sample particle in a medium like a fluid, which is displaced by a very large number of uncorrelated collisions on a molecular basis, b) the development of a predator–prey relations (e.g. snowshoe hare and Canadian lynx; only lynx shown) with fluctuation between two states[33,34] , c) a fatigue break after a number of stress cycles, and d) a development with two ‘parallel’ states (bifurcation) dependent on an external variation of a control parameter β.

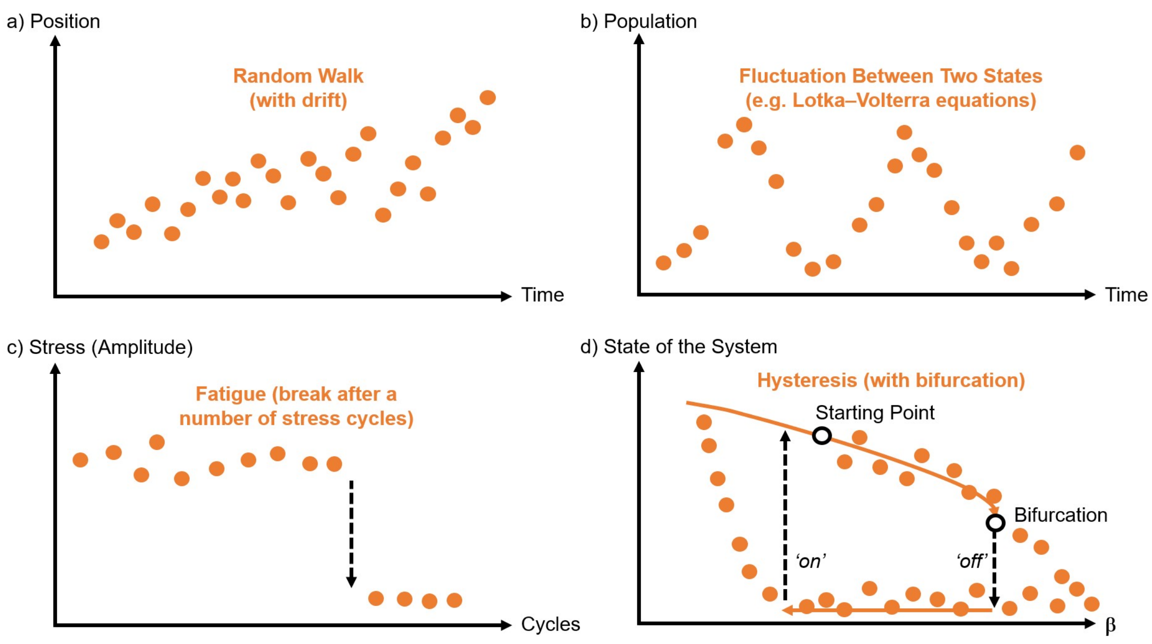
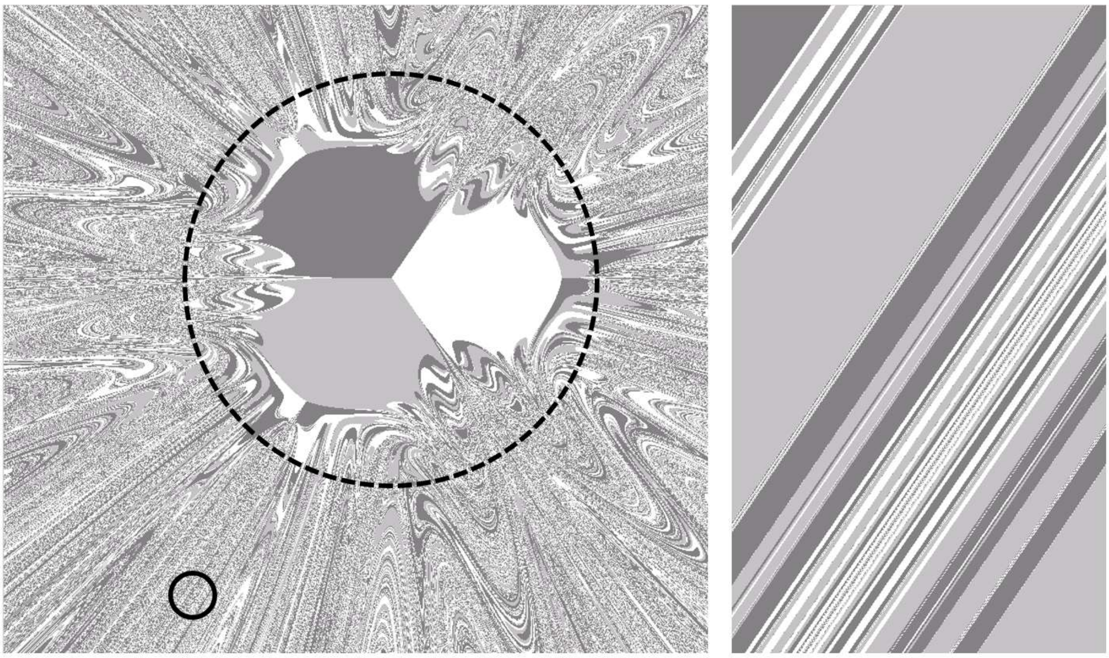


Figure 10.1: Examples for natural behaviour (for details see text)

[33] With much complicated behaviour compared to earlier simple assumptions of only two actors (Stenseth et al., 1997 and Krebs et al., 2018).
[34] Another example - described from a game-theoretical perspective - is the Diamond–Dybvig model for 'bank runs, deposit insurance, and liquidity' (Diamond and Dybvig, 1983) as a game with more than one Nash equilibrium (i.e. normal 'rational' behaviour of savers versus 'bank run').



$$\ddot{x} + \alpha/m\, \dot{x} + g/L\, x + \gamma/m \sum_{i=1,2,3} [((x-x_i)^2+(y-y_i)^2+d^2)^{-3/2} (x-x_i)] = 0$$

$$\ddot{y} + \alpha/m\, \dot{y} + g/L\, y + \gamma/m \sum_{i=1,2,3} [((x-x_i)^2+(y-y_i)^2+d^2)^{-3/2} (y-y_i)] = 0$$

Figure 10.2: The 'Magnetic Pendulum', i.e. a pendulum with an iron ball on a string under the influence of gravity and three magnets in the plane under the pendulum, with the 'chaotic' distribution of endpoints (over the 'black', the 'grey' or the 'white' magnet) depending on the starting point. The right insert shows a magnification of the circled area left. The differential equations are given at the bottom. For (most) starting points outside the dashed circle in the middle, it is practically impossible to predict an endpoint, although the system is fully deterministic[35]. The picture was produced with a computer program of Réne Matzdorf (www.physik.uni-kassel.de/1092.html) in 2010 by the author.

Whereas 'chance' plays a certain role in these examples – either in the sense of statistical mechanics in the description of the behaviour of systems of many independent participants like an ideal gas or Brownian Motion or in the sense of measurement noise due to uncontrollable external perturbation of many independent impacts – natural systems are described by equations of motion and typically differential equations, which can lead to an unpredictable 'chaotic' but deterministic behaviour. Unpredictability does not imply 'statistical' in any situation (see Fig. 10.2).

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[35] It is worth to remark that also 'chaotic' systems can be controlled and that it is possible to bring a 'chaotic' trajectory to a small neighbourhood of a desired location (see Boccalettia et al, 2000).

Therefore, it is essential to distinguish the different perspectives, how we can measure and describe our world:

- Physical processes can be defined as development of a natural system according to an equation of motion (usually set of differential equations), while measurements always have to deal with noise and the statistical error on the measured value.
- Probability is typically defined based on stochastic processes how future events depend on events in the past: an independent next value like in rolling the dice, a random next displacement based on current position like in random walk (Markov process), or a next value dependent on the difference of current and previous value (Lévy processes).
- Risk is always defined in the context of human decisions under uncertainty but with an objective function, what we want to achieve in future.

There is a variety of examples how these perspectives are mix and/or misunderstood. Some examples are worth to mention.

For the case of market risk, it is typically – and often unintentionally – assumed that market prises follow a Brownian Motion with a log-normal distribution of the increments. However, this is incorrect because:

- Not all physical Brownian Motions are Gaussian, but can be ‘Anomalous yet Brownian‘ (Wanga, 2009).
- Market prices can be described by a ‘Random Walk’ (see the seminal work of Eugene F. Fama, 1965, about efficient markets, which digest all available information in current prices, while allowing individual participants to follow different ‘opinions’, which introduce some noise to the market prices development), but that does not imply that prise increments are log-normal distributed.
- Market prices do follow (mostly) a Lévy Process, but this general category, which includes a Wiener process with a Gaussian distribution but also Lévy Distributions (see Mandelbrot, 1963).
- And Lévy Distributions exhibits heavy tail behaviour falling off according to a power law (sic!) with $x^{-3/2}$ for $x \rightarrow \infty$.

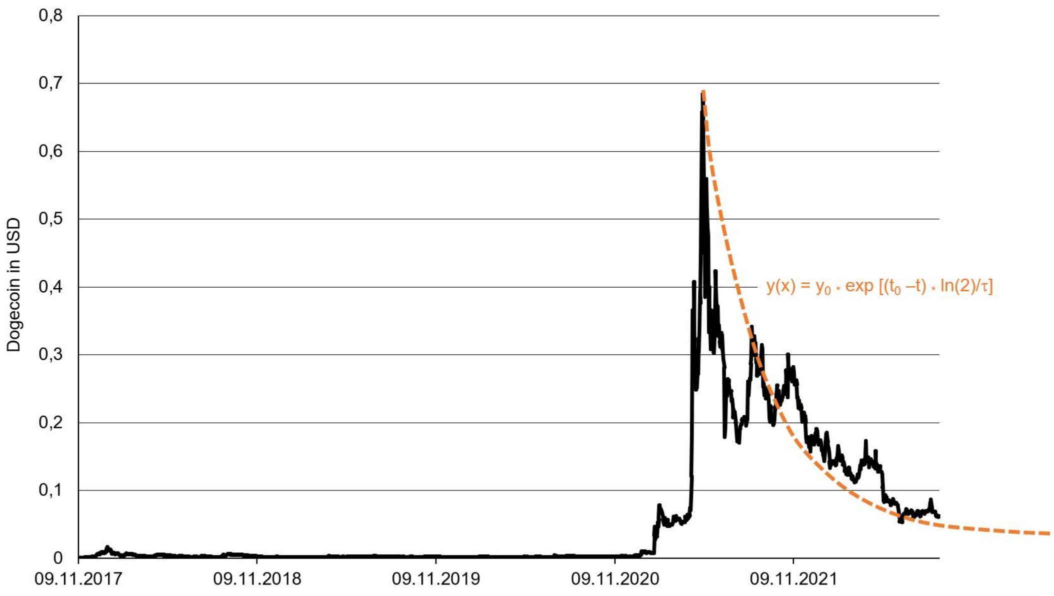


Figure 10.3: Dogecoin market price in USD and fit function with a half time life τ after Elon Musk mentioned Dogecoin in his 'Weekend Update' monologue on the 'Saturday Night Live' satirical news show on 8.5.2021.

Typically, market prices can be described by a (very general) random walk hypothesis, but this does not include any information about the distribution of prise increments - i.e. there can be (practically) infinite price changes for any selected time interval. Vice versa, ‘flash crashes’ are not excluded but within the range of definition of random walk processes. Nonetheless, the example in Fig. 10.3 reveals that for certain circumstances a market price development – in the 21st century of social media and news shows - can be triggered by a single event with a collective reaction afterwards. The Dogecoin case shows a ‘decay’ function for the price of this ‘crypto coin’ without any fundamental value, which was initiated as a pure joke at the beginning but revealed a peak of speculation after a public statement of Elon Musk.

In the case of credit risk, the Great Financial Crisis (GFC) revealed the importance of the assumption of independence (or missing correlation). However, the GFC emerged from the correlation (sic!) of overhyped subprime mortgages until 2007. This became – after the GFC – a textbook example of collective behaviour in financial markets.

Concerning operational risk (or 'non-financial risk' in financial services), we known that the behaviour of the probability distribution – the frequency-severity distribution – can follows a power law with 'fat tail'. Nonetheless, we do not know 'the' underlying processes[36], as there is a mixture of technical glitches, human errors, misconduct, simple fraud, and external attacks (especially in cyber risk), but also the result of (inadequate) regulation leading to errors. This is different for specific types of risk such as climate-change risk for banks, for which the general cause – i.e. global warming – is well-known, but the transmission from the physical cause to a financial loss is rather complicated (see next chapter).

For an ex-post evaluation of recorded events, a Bayesian probability is often a good way to describe events statistically – but often with the implicit assumption that the underlying process is a 'repeated game' (in other words: given events in an organisation follow the rules of a game). For any prediction of the future – for stock prices, credit defaults or availability of financial infrastructure – we can estimate future Bayesian probabilities ex-ante only with a very big BUT, which means that we assume that the future will be the past continued (i.e. with the same probability distribution). We can even calculate Value-at-Risk (VaR) and economic capital (based on VaR et cetera) – but these calculations hold true only for the part of the world, which behave as a 'repeated game'.

For extreme events, rare but severe losses and disruptions of operations, the is aa significant

Risk to believe in 'risk' as a repeated game

which might result in the illusion of risk control and missing operational resilience. The more we call on physical phenomena or statistical processes with easy features to calculate – normal distribution, finite mean values, thin tails – and the more we try to circumvent 'infinities', the more dangerous such an illusion of risk control can get.

[36] There is some typical pattern in operational risk that small problems pile up and trigger a kind of 'avalanche' with severe events at the end (see Milkau, 2022). Nonetheless, a direct comparison of a physical sandpile (as a model to analyse avalanches) and 'pile-up' of man-made problems in an organisation would be dangerous and would mingle physical effects like real friction with figures of speech to describe social interactions.

11. Climate-change Risk in Banking

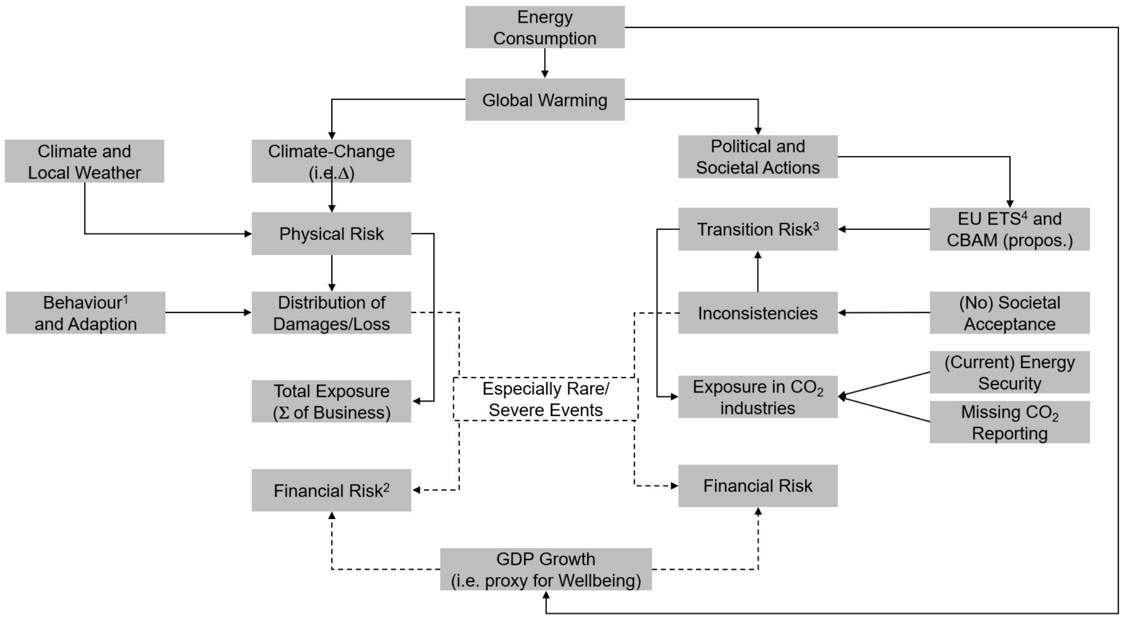
Any discussion about ‘climate-change risk’ in banking is – literally – a discussion about a change and, vice versa, no ‘repeated game’. While climate-change risk in banking has gained more and more attention for some years, it is an illustrative case for pitfalls concerning ‘risk’, because different perspectives are mixed. Although the European Central Bank / Banking Supervision (ECB, 2022) conducted a first 'climate risk stress test' in 2022, there is no general consensus how ‘climate-change risk’ should be defined. Definition for ‘climate-change risk’ include:

1. a new type of systemic risk, which would be a ‘singular risk’ without comparable data from the past, but a potential to ruin the financial system in general,
2. a transmission chain, how anthropogenic global warming and measures against climate change transmit to the economy, effect banks’ exposures (in ‘risky’ regions or ‘risky’ industries) and could result in prospective financial losses for banks, or
3. a call to steer credit to a ‘green transformation’ while banks are threatened with regulatory, litigation and moral risk for their ‘licence to operate’.

While the first definition relates to the backward-looking perspective of the Malthusian trap, the third one is (part of) a new risk for financial institution to be exploited for a political agenda, which might be agreeable, but which is not the task of a commercial agents. While we all – hopefully – support the concept of a ‘green transformation’, the best measure is a general and global carbon tax (or carbon emission fee).

This paper will focus on the second definition of ‘climate-change risk’ as an issue of transmission of man-made global warming along a long chain toward the impact on the banking industry.

A comprehensive overlook about ‘climate-change related risk’ is given in Milkau (2022c). For the purpose of this paper, the transmission chain of ‘climate-change risk’ can be simplified to the schematical structure in Fig. 11.1. While the physical mechanism of anthropogenic global warming is understood quite well, all future effects and predictions about the impact on the geophysical world and socio-economical systems have uncertainties depending on our limited strength-of-knowledge (see especially the IPCC reports in 2021 and 2022).



1) e.g. Expanding Bull's-eye Effect; 2) Total Financial Risk due to Physical Risk = Climate-related Risk + Climate-change Risk;
3) due to a 'Disorderly Transition'; 4) EU Emission Trading System and (proposed) Carbon Border Adjustment Mechanism

Figure 11.1: Schematical structure of the climate-change transmission chain. While 'Energy Consumption' results in 'Global Warming', energy is also a driver for 'GDP Growth', which is a proxy for the development of global 'Wellbeing'.

In her welcome remarks to the fifth annual conference of the of the European Systemic Risk Board in December 2021, Christine Lagarde (2021) summarized the principle '*Threats from Climate Change'*:

- *Climate change has become the defining challenge for our generation. ...*
- *The first is through physical risks. ... The flooding catastrophe this summer is estimated to have caused financial damages exceeding €29 billion in Germany alone. ...*
- *The second threat to resilience is through transition risk. A disorderly transition to a greener economy could also create losses for the financial sector, ...*

This separation into *physical risks* and *transition risk* is an established terminology, but blends very different mechanisms and analyse these two sub-categories in two perspectives: exposure (i.e. total amount of banks' loans to / investments in 'risky' geographic regions and 'risky' industries, but without any specification of a probability of default) and potential financial losses, which are currently not in scope of the ECB stress test.

The challenges to derive estimation for future fat tail events due to physical effects such as heavy rain/riverine floods or droughts (or cascading effects of both!) were already elaborated in the chapters 2 and 4 with the – very sadly – experiences of German Ahrtal in 2021. While it is possible – and required in the ECB stress test – to derive financial exposures for mortgages and loans provided in flood-prone regions, it would require an entanglement of 'normal' climate-related catastrophes and climate-change triggered 'additional' events (see Milkau, 2022c). Additionally, there are shifts due to human behaviour (such as increased settlement in 'risky' regions) and adaption (such as better water management systems). Consequently, an overall exposure can be estimated based on some assumptions, but an entanglement of historically recorded time series and 'additional' climate-change related development plus human behaviour minus adaption is an open exercise (and would include a number of assumptions and both, statistical and systemic, uncertainties).

This transmission chain is characterised by strong non-linearities, as thresholds effects occur at each step: An increase of e.g. smaller riverine floodings will not result in (unusual) damages, only 'peaks over threshold' of damages will impair the financial condition of citizens and corporates and, finally, climate-change related damages have to be separated from 'normal' catastrophes, which in the case of Ahrtal happen once in a century.

The situation is even more tricky for 'transition risk' as any baseline of '*disorderly transition to a greener economy*' raises the question what the orderly transition path would be. The European Union is one of the very few places in the world with a carbon emission trading system (ETS) plus proposal for a border tax on 'imported carbon emissions (CBAM). Whereas EU ETS + CBAM are still incomplete[37], some countries such as Germany follow counterintuitive initiatives with de-facto ban on carbon capture and storage (CCS) and an exit strategy from carbon-free nuclear energy.

[37] Currently, the EU ETS covers the following sectors and gases, focusing on emissions that can be measured, reported and verified with a high level of accuracy: (a) CO_2 from (i) electricity and heat generation, (ii) energy-intensive industry sectors including oil refineries, steel works, and production of iron, aluminium, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids and bulk organic chemicals, (iii) commercial aviation within the European Economic Area; (b) N_2O from production of nitric, adipic and glyoxylic acids and glyoxal; and (c) perfluorocarbons (PFCs) from production of aluminium. The EU ETS does – for the time being – include neither traffic and heating, nor agriculture.

There seems to be a lack of understanding how a ETS with a cap on carbon emission works (in the European Union) and that any domestic intervention in carbon markets do only result in a shift but no further reduction[38]. It is also worth to note that the 'emission allowances' according to EU ETS – literally – allow companies to emit CO_2, which contradicts arguments made in cases of 'Climate Litigation' before courts that there is an unwritten '*duty of care*' towards third parties to reduce CO_2 emissions.

These examples might be illustrate that a '*disorderly transition'* is more the rule than an exemption. Consequently, financial losses con result from political decisions, which seem to be unpredictable especially when based on isolated arguments. This political risk of non-rational action might be the real 'risk' of climate-change for the financial industry, which is now amplified by the question of energy security in Europe as a very tangible and short-term risk. Additionally, any fragmented and expansive[39] solution will be a negative example for other countries and ensuring them to take a game-theoretical approach with most benefits for their citizens.

Additionally, a tendency emerged in the public debate to focus on so-called 'tipping points' (see Box 3 for detailed explanation). On the one side any 'tipping point' is – literally – a singular event and the opposite of a 'repeated game'.

Independent from the scientific details (as elaborated in Box 3) the notion of 'tipping point' as threshold towards an irreversible global catastrophe is the contemporary example of Luhmann's *Katastrophenschwelle*. As any awareness for such a *Katastrophenschwelle* is beyond objective criteria. The societal and political reactions are not predictable - and represent a 'risk' by themselves.

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[38] Within the EU ETS the carbon emissions are capped based on the available emission allowances for defined time intervals. As the allowances are tradable, any 'local' reduction will allow 'free' allowances to be used elsewhere – and in total no reduction effect is achieved (as long as the whole number of allowances is not reduced at all).

[39] Alexandra Jour-Schroeder, Deputy Director General of the European Commission´s Directorate-General for Financial Stability, Financial Services and Capital Markets Union, gave an indication in an interview (Jour-Schroeder, 2022) when asked how the European Commission wants to provide the enormous amounts of funds that are necessary to finance the transition to a sustainable economy: *'Let´s be honest: this is a rather daunting task. Europe will need an estimated EUR 350 billion in additional investment per year over this decade to meet its 2030 emissions-reduction tar-get in energy systems alone, alongside the EUR 130 billion it will need for other environmental goals*.'

The term ‘*tipping points*’ was popularized by Timothy M. Lenton et al. (2008). The development of this term is an appreciated attempt to translate complicated scientific research into wakeup calls to act against global warming. Nonetheless, the societal communication of scientific results could result in over-simplification such as ‘*irreversible tipping points*’. In the recent reports of the IPCC (2021), there is already a difference between the Summary for Policymakers and the technical chapters [following quotes from the IPCC report].

Summary for Policymakers (Footnote 34): *A tipping point is a critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly.*

Box TS.9: Irreversibility, Tipping Points and Abrupt Changes: *The present rate of response of many aspects of the climate system are proportionate to the rate of recent temperature change, but some aspects may respond disproportionately. ... tipping elements exist in the climate system where processes undergo sudden shifts toward a different sensitivity to forcing, such as during a major deglaciation, where one degree of temperature change might correspond to a large or small ice sheet mass loss during different stages.*

An illustrative example for possible misunderstandings in the public debate is perception of an ‘abrupt’ shutdown of Atlantic Meridional Overturning Circulation (AMOC): There is an awareness that AMOC could collapse ‘tomorrow’ with resulting weather hazards and ‘physical risk’ for agriculture, economy, and the financial system. However, a model simulation in the IPCC report for an assumed slowdown of the AMOC revealed [quote]: *There is medium confidence an abrupt collapse will not occur before 2100; for 1.5-2, 2-3, 3-5°C warming in 2100, AMOC decline is 29, 32 and 39%, respectively, of its pre-industrial strength*.

In the seminal work of a possible shutdown of AMOC, Stefan Rahmstorf (1995) described the *'Bifurcations of the Atlantic thermohaline circulation in response to changes in the hydrological cycle*' and Rahmstorf et al. (2005) presented a schematic model of the ‘*Thermohaline circulation hysteresis*’: Increasing freshwater forcing from the melting of Greenland Ice Sheets changes the North Atlantic Deep Water (NADW) flow. The NADW is decreasing non-linearly up to a so-called ‘bifurcation’ beyond which no NADW formation can be sustained. At the bifurcation[40] the NADW will ‘switched off’ and a decrease of freshwater input cannot change back to normal until a much lower freshwater forcing.

Another example is a recent research article (McKay et al., 2022) on 'Exceeding 1.5°C global warming could trigger multiple climate tipping points'. This article summarized different model estimations from literature for so-called tipping points such as Greenland ice sheet (GrIS;

[40] A discussion how such bifurcations could be anticipated was already given in Dakos et al (2013) *'Flickering as an early warning signal*'.

being the major driver of AMOC[41]) and it quotes: *'Greenland ice sheet (GrIS) ... is shrinking at an accelerated rate ... with approaching a tipping point in west Greenland ... Different models give a critical threshold of ~1.6°C (0.8 to 3.2°C)* [Ref. of 2012]*, ~1.5°C* [Ref. of 2020]*, or 2.7±0.2°C* [Ref. of 2021]. *... A coupled ice sheet-atmosphere model found no collapse threshold [Ref. of 2020], leading AR6 to state that there is limited evidence for irreversible GrIS loss below 3°C. … Our best estimates for GrIS include a threshold of ~1.5°C (0.8 to 3°C) (high confidence), timescales of 10 ky (1 to 15 ky) (medium confidence), ...'*

This article applies a visualisation in form of a bar chart ranging from yellow (for data point of 0.8 degrees) to deep red (for data point of 3.0 degrees). This visualisation resembles the style of the IPCC reports with so-called 'burning embers' charts, which indicate the level of impact of global warming for different Reasons for Concern (RFC) according to undetectable (white), moderate (yellow), high (red) or very high (violet).

Such simplifications, i.e. impact depending on temperature rise (IPCC) versus model estimations (McKay et al., 2022), may be well-intentioned but can lead to misunderstandings. While the IPCC AR6 concludes '*limited evidence for irreversible GrIS loss below 3°C*', McKay et al. show a graph with an indication of an estimate (derived by an undisclosed method) at only 1.5 degrees. It is regrettable that this paper did neither provide a best global estimation (weighted average) nor a summary of best available models (with lowest uncertainty) but uses some selection of studies with different model predictions.

Similar to the events in German Ahrtal, an analysis of historical climate records can help to put all those model estimations in context. As recent study on 'Medieval warmth confirmed at the Norse Eastern Settlement in Greenland' (Lasher and Axford, 2019) found [quote]: '... *brief warm period interrupted a consistent cooling climate trend driven by changes in Earth's orbit. … the climate was about 1.5-degrees Celsius warmer than the surrounding cooling centuries. This warmer period was similar to southern Greenland's temperatures today, which hover around 10-degrees Celsius (50-degrees Fahrenheit) in summer*. … In some areas, it appears that recent increases in snowfall at high altitudes have partially counteracted recent increases in melt at low altitudes.' While this analysis supports the sensitivity of GrIS as indicator of global warming, it also made clear that a 1.5 degrees temperature jump occurred before and without irreversibility.

Box 3: The debate about 'tipping points' and time-scales

[41] Recently, Khan et al. (2022) reported *'Accelerating Ice Loss From Peripheral Glaciers in North Greenland*': While only 4% of Greenland's ice are small peripheral glaciers - distinct from the ice sheet – they are responsible for 11% of Greenland's ice loss. Any accelerated dynamics requires better insight into the underlying interlinked processes to understand sea level rise contribution (see also Khan et al, 2022b)

Potentially, the statement of Larry Fink (2020), CEO of Blackrock could be seen as a guideline: '*Climate Risk Is Investment Risk'*. There was a lot of discussion, but the essence might be the insight that the singularity of climate-change risk for humanity (as we never faced more global warming in the last 2000 years as predicted for 2100 compared to pre-industrial times) requires a portfolio approach with a diversity of investments representing a diversity of ways to deal with global warming in times of uncertainty. Larry Fink (2022) elaborated on his opinion [quote]:

> *The transition to net zero is already uneven with different parts of the global economy moving at different speeds. It will not happen overnight. We need to pass through shades of brown to shades of green. For example, to ensure continuity of affordable energy supplies during the transition, traditional fossil fuels like natural gas*[42] *will play an important role both for power generation and heating in certain regions, as well as for the production of hydrogen. ... Capitalism has the power to shape society and act as a powerful catalyst for change. But businesses can't do this alone, and they cannot be the climate police. That will not be a good outcome for society. We need governments to provide clear pathways and a consistent taxonomy for sustainability policy, regulation, and disclosure across markets.*

This elaboration can be regarded as a good summary how to regard a singular challenge as climate-change, which is without any recorded experience and, trivially, is beyond any 'repeated game'. Consistent measures against climate-change are a problem of international co-operations – and can be seen as a game-theoretical challenge (see Ockenfels and Schmidt, 2019; Wambach, 2022; for data see Fig. 11.2).

As about half of the CO_2 emission in 2020 was generated by countries with autocratic regimes, it is unclear what long-term incentives can be offered to the leaders of those states to avoid a 'repeated game' that industrial states invest (successfully) in the decrease of CO2 emissions whereas especially those autocratic countries benefit from 'cheap' fossil energy.

[42] Of course, the transition of currently high-emission industries including energy production requires significant funding. However, examples such as financing of LNG terminals was regarded as 'non sustainable' – until the Russian attack on Ukraine. Especially in Germany, new LNG terminal are now top priority with a shift of paradigm towards energy security for citizens and the economy.

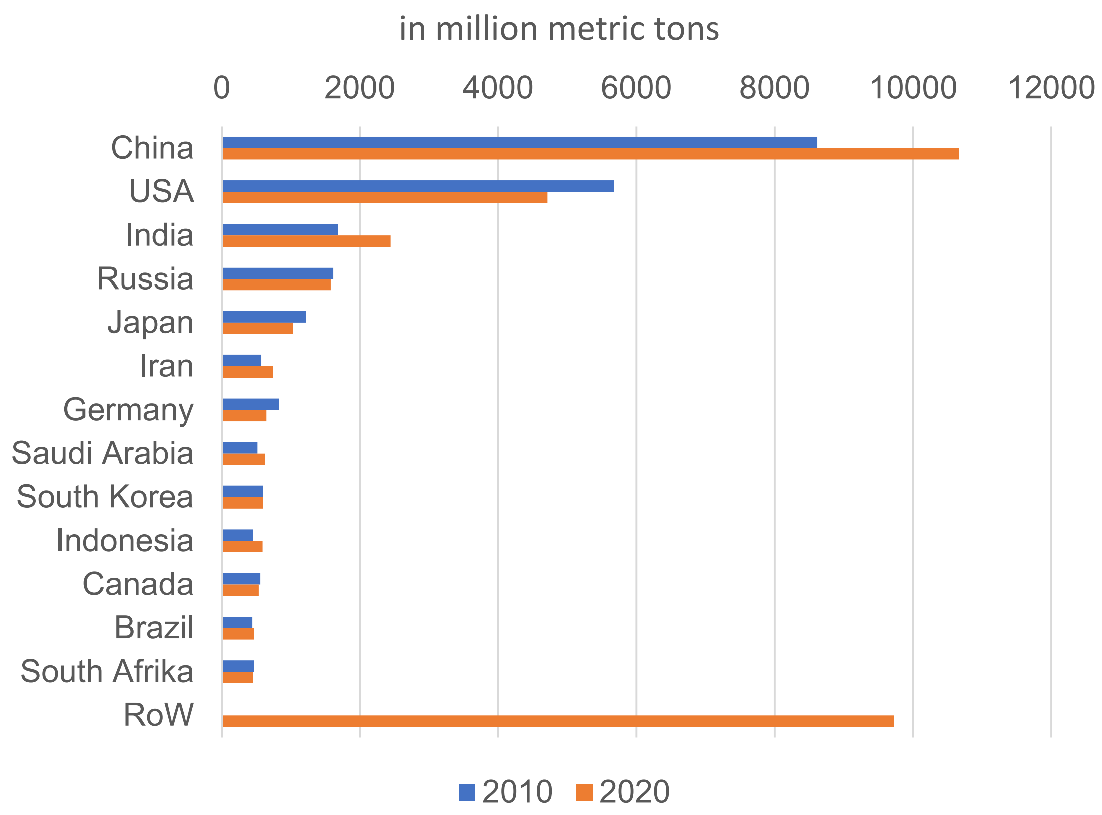

Figure 11.2: Top-CO_2 emission countries in 2010 and 2020 (data: Statista, 2022). The shares (with China: 30%, Rest-of-World: 28%, industrial states only ~33%) and the development reveals that global measures require international co-operation.

William Nordhaus (2015) proposed an idea for 'Climate Clubs' as an idealized solution of the free-riding problem with global public goods (based on game-theory – sic!). While the idea that countries build a club with a defined carbon tax and sanction non-participants is compelling, it is questionable whether autocratic leaders would 'play' according to those idealized rules.

As Mr. Xi Jinping, China's leader, said in a report to the Communist Party's national congress in Oct. 2022 *'Coal will be used in a cleaner and more efficient way'* (quoted from New York Times: Bradsher and Krauss, 2022). A recent report by UN Climate Change (2022) revealed that [quote]: *'combined climate pledges of 193 Parties under the Paris Agreement could put the world on track for around 2.5 degrees Celsius of warming by the end of the century'*.

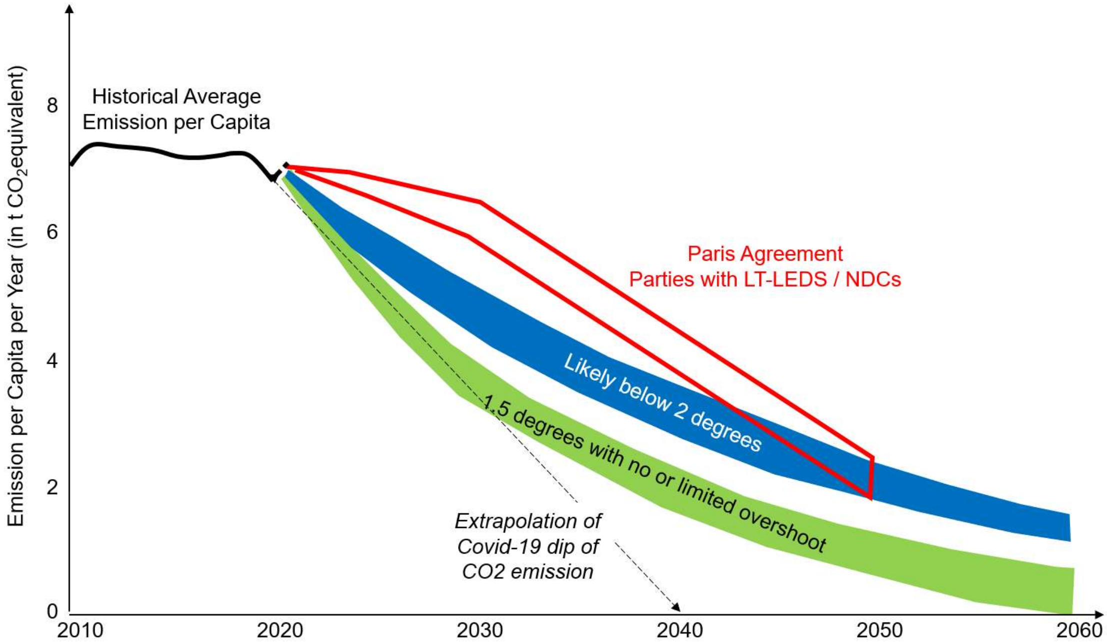

Figure 11.2: Comparison of pledges with pathways and schematic extrapolation of Covid-19 dip of CO2 emission (data taken from: UN Climate Change, 2022; LT-LEDS stands for Long-term-Low-emission-development-strategy)

In other word, the nationally determined contributions (NDCs) are potentially not sufficient to achieve the Paris Agreement to limit global warming at 2.0 degrees Celsius by 2100 and try to reduce this temperature rise to 1.5 degrees Celsius by the end of the century. In addition, a NDC is a pledge but not a delivered measure.

Figure 11.3 demonstrates a comparison of pledges with calculated pathways for global CO_2 emission and schematic extrapolation of Covid-19 dip of CO_2 emission (data taken from: UN Climate Change, 2022). A vision to reduce CO_2 emission until 2040 on a <u>global</u> scale would require a reduction similar to the Covid-19 dip – but every year for about two decades. As many economies struggled (and not all are recovered yet) from this unprepared one-year dip, a harsh reduction strategy would be a disaster for the global economy, a set-back before the Great Enlightenment and catapult billions of people into anti-modern times of poverty and starvation[43]. And, especially, the transition to 'net zero' requires tremendous clean energy investments including supply chain, electricity grids, storage technologies for electricity (beyond simple battery stacks) and CCS.

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[43] Which would be the result of ideas as Bruno Latour together with Nikolaj Schultz (2022) *"nouvelle classe écologique"* ... 'fighting against the horzion of production, returning to smaller forms of subsistence such as permo agriculture' (Sciences Po, 2022).

A country like Germany is even exiting CO_2-free nuclear power production, introduced *de-facto* a ban on CO_2-removing Carbon Capture & Storage (CCS), and is committed to replace its former dependency on imported Russian natural gas by a ‘planned’ future dependency on importing ‘green hydrogen’, which is not yet available in commercial quantities for long and represents an unpredictable risk for the whole economy. Only few countries – such as the European Union incl. Germany, USA and Japan – achieved real reduction of CO_2 emission up to now. In other words, only states with very strong economies and high GDP can afford to ‘invest’ in reduction measures.

In a recent report, the European Union (EU, 2022, Fig. 2) published a figure ‘*EU-27 net domestic GHG emissions*’ with a linear extrapolation of the emission reduction 2017 to 2019 (of about 120 Mt CO_2 equivalent per year), which would meet a Net-Zero target in 2050 for EU-27. However, the large dip in 2020 (-8.8%) and recovery in 2021 (+5.2%) illustrate that such short-term trends should be treaded carefully and not extrapolated without understanding the context. A large part of the reduction of the recent years resulted from replacement of coal by natural gas – and especially Russian gas in countries like Germany. While one can hope to replace natural gas by ‘green hydrogen’ in a far future (assuming that the countries producing ‘green hydrogen’ will not need this production for their own growing energy demand), there is a large gap between currently available technologies and this vision of ‘green energy’ in 2050 in the European Union.

On a national level, the German expert council for climate questions (Expertenrat für Klimafragen, 2022) summarized [quote; in original German]:

> *Gelingt es nicht, den schnellen Umbau zu realisieren, wird ein Erreichen der Klimaziele nur möglich sein, wenn andere Hebel, wie zum Beispiel ein Rückgang der Aktivitäten, beispielsweise mit entsprechender Änderung im Konsumverhalten, stärker adressiert werden. ... Dabei kann das Leitbild der harten Mengengrenze und der Klimapolitik als Wirtschafts- und Sozialpolitik die Perspektive der deutschen Treibhausgasminderung deutlich weiten. Denn damit könnten die gesellschaftspolitischen Voraussetzungen dafür geschaffen werden, dass die Einführung einer harten Mengengrenze ermöglicht wird. Unabhängig vom geschilderten grundlegenden Wechsel des Paradigmas ...*

This conclusion is an euphemistic description. What this summary determined as a 'shift of paradigm' would be a first step towards a planned economy with an extreme increase of the cost for heating and mobility for all citizens but without a availability of the technologies such as sufficient, reliant and secure electric energy production, missing capacities of ‘green hydrogen’ (but with new dependencies on autocratic regimes, as this ‘green hydrogen’ has to be imported) and even unrealistic assumption about new heat-pumps to be installed[44].

While we all would be happy to achieve the targets of the Paris Agreement as soon as possible, the costs and damages of global warming have to be balanced with the costs and damages due to measures against global warming. Although it may sound counterintuitive first, only global GDP growth - together with adaption and human ingenuity – can provide a basis, on which CO_2 emission reduction is economically feasible and - especially – socially acceptable. Simply taking the status-quo and extrapolating old measures (used in wealthy societies) on a global level would be wish-full thinking.

The recent 'World Energy Outlook 2022’ of the International Energy Agency (IEA, 2022) pointed out [quotes]:

- *Policy and technology progress since 2015 has shaved 1 °C off projected warming, a step in the right direction but much more needs to be done in order to avoid severe climate disruptions*
- *Today’s policy settings are now sufficiently strong that they produce a distinct peak in fossil fuel use before 2030*
- *Government responses to today’s energy crisis are marking this out as a major turning point towards a cleaner and more secure energy system*

[44] Other proposals are making the same mistake to ignore the requirements for proposed solutions. An extreme example is the vision of George Monbiot (2022) to abandon agriculture and shift food production to large-scale, industrial, bio-reactor synthesis of proteins [quote]: ‘*We face what could be the greatest predicament humankind has ever encountered: feeding the world without devouring the planet. Already, farming is the world’s greatest cause of habitat destruction, ... As luck would have it, the enabling technology has arrived just as we need it. Precision fermentation, producing protein and fat in breweries from soil bacteria, fed on water, hydrogen, CO2 and minerals, has the potential to replace all livestock farming, ...*’. Unfortunately, this vision includes a ‘planning’ of everybody’s life including nutrition, generated new ‘risks’ due to dependency on one industrial technology (triggering an analogy to the science fiction movie ‘*Soylent Green*’ of 1973), and establishes new dependencies as such a protein synthesis from scratch requires tremendous amounts of (i) ‘green energy’ and (ii) ‘green hydrogen’, which would have to be imported especially from autocratic regimes.

Consequently, climate-change risk for banks is not a mere statistical exercise but a very dynamical socio-economic development, which requires a realistic approach instead of mere vision of a static better world. The main 'risk' in climate-change risk for banks is the unpredictability of (occasionally inconsistent and sometimes non-rational) political decision-making.

Nonetheless, Frank Elderson (2022), member of the ECB's Executive Board, wrote in a recent blog [quote]:

> *First, we detected blind spots at 96% of banks in their identification of climate-related and environmental risks in terms of key sectors, regions and risk drivers. Where banks do assess the risks, they are not yet able to grasp the full magnitude as most do not actively collect granular counterparty and asset-level data. And almost all boards are still unaware of how these risks will develop over time, what precise risk level the bank can accept and what action it will take to rein in excessive risk. ... For instance, some banks have committed to reaching net-zero emissions by 2050 but fail to define "net zero" and fail to set interim targets. ...*

This granularity of statistics is definitively a major problem to calculate a climate-change risk in banks and to (i) discriminate traditional severe weather events from additional events due to global warming and (ii) entangle increased climate-change related damages from adaption and from antagonistic human behaviour (especially the 'expanding bull's-eye effect').

Typically, banks lack time series of credit defaults with a 'climate' label, about which defaults were triggered by weather events (particularly private mortgages and corporate loans), that banks could try to subtract an 'background' of normal weather events by using a proxy such as 'increase in temperature', which can help to estimate the surplus due to the additional climate-change related contribution and tread this surplus as 'peaks over threshold'. So banks have to start from scratch and correlate historical time series of credit defaults in climate-prone areas – again a proxy approach – with known historical extreme weather events (from riverine flooding and costal floods to droughts in agricultural areas) to simulate weather-related defaults and afterwards subtract the 'normal' weather events as background.

However, the mentioned history in the Ahrtal indicates that there was a 90 year long weather time series, whereas ‘normal’ extreme floods occurred about 200 and 100 years before – i.e. outside the recorded timeframe.

Any calculation beyond simple exposures (i.e. loans in critical regions) requires very sophisticated statistical methods and models, which are rather uncommon in banks today and demand more research.

12. Credit Scoring as ‘High-Risk’ Application in the EU AIA

A final issue is a tendency to use the term ‘risk’ without quantification at all. An illustrative example is the proposal of the European Commission (2021) for an ‘Artificial Intelligence Act’ (AIA) classifying of credit-scoring systems as ‘high-risk AI systems’ in general. As a comprehensive discussion is given in Milkau (2022d), only the aspect of ‘risk’ will be elaborated in this paper.

It was quite remarkable that Simon Burton explained at the Jahrestagung der Deutschen Sektion der Internationalen Juristen-Kommission [quoted according to Gelinsky, 2022]: ‘*Es bestehe bereits Unsicherheit darüber, was genau Künstliche Intelligence risikoreich macht*.’ And Martin Eifert elaborated at the same event [quoted according to Gelinsky, 2022]: ‘*Die Sorge vor fehlerhaften KI-Entscheidungen verdrängt die eigentlich bekannte Fehleranfälligkeit menschlicher Entscheidungen*.’

In the case of the ‘Artificial Intelligence Act’, the AIA uses an uncommon, extended definition what ‘Artificial Intelligence’ should include: from machine learning to rule-based system and traditional statistical approaches (Annex I[45]). In parallel, the AIA contains an arbitrary collection of (i) products, (ii) public services and (iii) few offerings of the private economy with embedded Artificial Intelligence, which are defined as ‘high-risk’ without systematics: from automated vehicles and medical devices to law enforcement or border control management (AIA Annex II and III).

Product safety is already regulated in the European Union, new types of cars or medical technology require a comprehensive certification process, and the question of algorithmic systems in law enforcement et cetera is a general one beyond a specific technology like Artificial Intelligence in a narrower sense.

However, an overall justification for the AIA is a general skepticism towards technology as already described in the ‘Presidency conclusions - The Charter of Fundamental Rights in the context of Artificial Intelligence and Digital Change of the Council of the European Union’ on 21.10.2020 [quote, underlying by the author]:

[45] Definition of AI according to AIA ANNEX I referring to AIA Article 3, point 1 [quote]: '(*a) Machine learning approaches, including supervised, unsupervised and reinforcement learning, using a wide variety of methods including deep learning; (b) Logic- and knowledge-based approaches, including knowledge representation, inductive (logic) programming, knowledge bases, inference and deductive engines, (symbolic) reasoning and expert systems; (c) Statistical approaches, Bayesian estimation, search and optimization methods*.’

'*However, while digital technologies, including AI, present increasing opportunities and benefits, their design, development, deployment, and misuse <u>may also entail risks to fundamental rights</u>, democracy and the rule of law*.'

This quote reveals that 'risk' is used instead of 'threat'. Although fundamental rights are – traditionally – personal rights against violations by the state and governmental restrictions of individual freedom, this concept was extended to the private banking sector in the case of credit scoring.

Since the beginning of banking, lending involves a <u>credit risk taken by a lender</u>, and the lender always suffers from an information asymmetry. Additionally, the European 'Directive ... on consumer credits' (2021/0171) states an '*Obligation to assess the creditworthiness of the consumer*' in Article 18 [quote]: '*... creditor … makes a thorough assessment of the consumer's creditworthiness. That assessment shall be done in the interest of the consumer, to prevent irresponsible lending practices and over-indebtedness'.*

However, this regulatory obligation is regarded as a potential 'risk to fundamental rights'. The AIA elaborates [quote, underlying by the author]:

(1.1. Reasons for and objectives of the proposal) … The proposal lays down a solid risk methodology to define "high-risk" AI <u>systems that pose significant risks to the health and safety or fundamental rights of persons</u>. …

(Recital 37) Another area in which the use of AI systems deserves special consideration is the access to and enjoyment of certain essential private and public <u>services and benefits necessary for people</u> to fully participate in society or to improve one's standard of living. In particular, AI systems used to evaluate the credit score or creditworthiness of natural persons should be classified as high-risk AI systems, since they determine those <u>persons' access to financial resources</u> or essential services such as housing, electricity, and telecommunication services.

AI systems used for this purpose may lead to discrimination of persons or groups and *perpetuate historical patterns of discrimination*[46,47]*, for example based on racial or ethnic origins, disabilities, age, sexual orientation, or create new forms of discriminatory impacts. …*

It needs be pointed out that this '*access to financial resources*' is antagonistic to the requirements of the Directive (2014/92) on '...*access to payment accounts with basic features*' because these '*financial resources*' are simply the lenders' money.

As indicated in Box 4, there is always a danger to correlate a (not used) sensitive parameter with the result of a decision-making algorithm. However, any simple correlation does never indicate any discrimination without a careful inspection of the causal relations (see: Pearl with Mackenzie, 2018).

Both examples in Box 4 reveal that such as causal analysis with a directed graph show that a sensitive attribute can be connected via a so-called 'mediator' to a result: In the case of credit scoring, it is true that women in Germany have a lower income compared to men (the so-called 'gender pay gap'[48]) and – in a very simple model – get less consumer credit approvals. But if corrected for 'similar economic conditions' there is no difference – and no discrimination.

[46] One often quoted 'example' is the Apple Card case of Nov. 2019 with complains about discrimination that the underwriting bank would offer lower credit limits to female applicants (but with rather traditional statistical credit scoring without any AI). However, the New York State Department of Financial Services (DFS, 2021) summarized the findings of an investigating [quote]: *'No Fair Lending Violations Found … In reality, however, underwriters are not required to treat authorized users the same as account holders, and may consider many other factors. In terms of gender, the Department found, based on its data analysis, that Apple Card applications from women and men with similar credit characteristics generally had similar outcomes*.'

[47] It should be noted that the '*processing of special categories of personal data*' is already prohibited in the European General Data Protection Regulation (GDPR, Art. 9, 4.5.2016), and anti-discrimination regulations have been in place since 2000 (the EU Race Equality Directive of 29.6.2000 and the Framework Employment Directive of 27.11.2000).

[48] There is also a long-lasting debate about a 'statistical discrimination' – typically concerning employment (see e.g. Escudé, 2022) – when two populations differ concerning the 'noise' information signal of a participant concerning an ability such as compatibility to a job offer. Of course, this is the case for applicants without qualification documentation (especially migrants without certification documents et cetera). Any sub-population with a certain skill, but without any documentation about this skill will require more costs for assessments. This is a stylized case, as today in a country such as Germany people have certification about education, there is a huge demand for employees (with many open positions), and many jobs are linked to tariff commitments. On the one side, this concept of 'statistical discrimination' does not help to explain the 'gender pay gap' (as men and women have the same 'signals' about their qualification). Whereas on the other side there are some (few) specific cases for sub-populations without sufficient 'signals' such as especially self-employed people in case of a loan application without the required regular income statements.

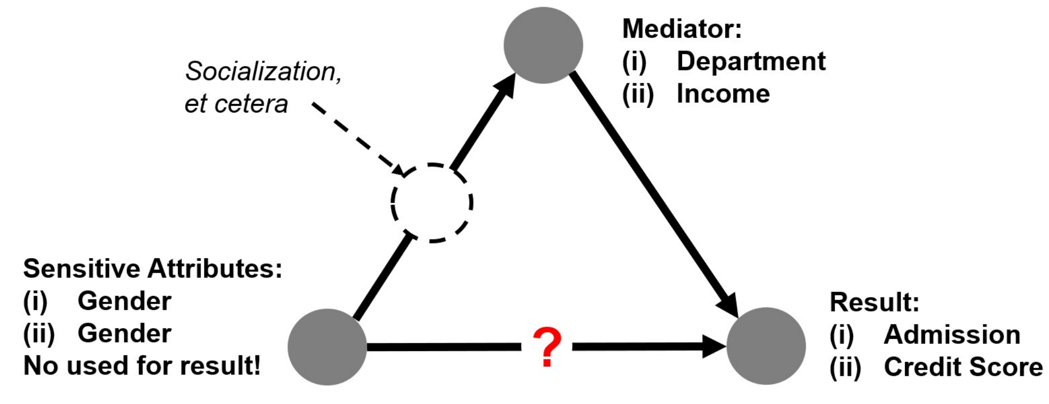

Figure 12.1: Examples for the (i) 'Berkeley Admission Paradox' and (ii) 'Gender Pay Gap' as directed graphs indicating a causal relationship[49]

The issue of 'perpetuation of historical patterns of discrimination' is illustrated in Fig. 12.1 with the (i) *'Berkeley Admission Paradox'* and the *(ii) 'Gender Pay Gap'*. The motivation is a statement of the German Datenethikkommission (2019) concerning a possible discrimination in credit scoring [quote, Teil F, Kap. 2.6 in the original]: *'Im Rahmen der Schätzung der Kreditwürdigkeit wird das Haushaltseinkommen als Information verwendet. Dieses fällt in Deutschland für die Geschlechter im Mittel unterschiedlich aus. In der Folge kann ein algorithmisches System, welches das Haushaltseinkommen verwendet, zu unterschiedlichen Verteilungen der Schätzungen für die Kreditwürdigkeit von Männern und Frauen gelangen*.'

While the '*Gender Pay Gap'* is true, it does not constitute any discrimination. This situation is analogue to the example in 1973 the University of California in Berkeley found that 44% of the men who applied at Berkeley graduate school were accepted, compared to 35% of the women. Did the university discriminate women? While this was the outcome of statistical methods on an aggregated level, a careful analysis on the level of departments found that there was no discrimination.

A higher proportion of women applied to the humanities and social sciences with a higher number of applicants but a smaller number of places (and vice versa more men applied for 'hard sciences' like engineering or computer sciences with more

[49] A similar, but more complicated case is of the US start-up lender 'Upstart' using alternative data – such as the quality of education – to estimate credit scores (see: Consumer Financial Protection Bureau – CFPB, 2019). While there is no direct relation between 'race' and 'student loan interest rate', there is a Mediator chain: Race → Parents' Income → Selection of Education (= Cost of Collage) → Quality / Reputation of Degree → Future Employment / Salary → Probability of Re-payment → Risk-based Interest Rate. This chain of causality was not taken into account by a lobbying organisation (SBPC, 2020) claiming a discriminatory '*Education Redlining*' - based on three pre-selected cases.

places and, trivially, more acceptances). Similarly, there IS a '*Gender Pay Gap'* in Germany, which results in a lower (household) income of women, but if corrected for similar economic characteristics credit scoring provides similar results for men and women.

Box 4: Simple correlations and causal relations

This difference between simple correlations of (randomly selected) parameters and a causal description of a certain case should be understood before any attribution to a 'risk' category. However, the current proposal for an AIA does not go so far.

This is a change of paradigm from 'risk' as probable loss of lenders' money towards a new kind of "*risk*" of borrowers if their creditworthiness is accessed as legally required. Maybe this is a singular example, but it illustrates a strange development from 'Bankers of Puteoli' to the opinion of the European Commission what 'risk' is, and it represents a growing 'political risk' for the market economy in an open society.

A final remark concerning the tendency to classify some technology as a 'risk' for fundamental rights is a recent statement of the European Data Protection Board (2022) '*on the design choices for a digital euro from the privacy and data protection perspective*', which was adopted on 10.10.2022. Independent from the discussion, whether a Digital Euro has a convincing use case or not, the EDPB's statement is remarkable [quote, underlying by the author]:

> *'… digital euro ... the possible high risks for fundamental rights and freedoms that the deployment of such project could entail for European citizen, ... In order to meet the policy objectives enshrined in Articles 7 and 8 of the European Charter of Fundamental rights and the high privacy standard that only the public sector can offer, it might not always be appropriate to foresee a validation of transactions by a third party. The regulatory checks, if needed, as a rule should be run ex post and on a targeted basis, ..."*

As a Digital Euro would be an alternative digital means of payments additional to SEPA credit transfer / direct debit, card transactions, paying with providers such as PayPal et cetera, the classification of '*Digital Euro = possible high risks for fundamental rights and freedoms*' is a further example for the development of 'political risk' in Europe, which discloses a fundamental skepticism concerning technology and which follows an 'anti-modern' way of discourse.

13. The Illusion of Risk Control

The title '*The illusion of risk control - What does it take to live with uncertainty?*' is taken from a small booklet edited by Gilles Motet and Corinne Bieder (2017) about industrial safety management. But it also holds true for risk management in financial services and other organizations. Although this booklet does not refer to 'repeated games' it follows a similar approach as in this paper. While the whole booklet is worth to read, some points are worth to mention [quotes]:

- *Uncertainty gives a new perspective on safety*. (Gilles Motet, Chapter 1)
- *And risk is always an interpretation, in a multi-dimensional, social and complex interpretive field.* (Jean Parès, Chap. 4)
- *If the questions of moral responsibility and societal benefits were certainly raised … and integrating them into a broad dynamic societal risk management framework* (Corinne Bieder, Chap. 8)

The more we leave the realm of '*repeated games*' with calculable probabilities and when we look to rare, but severe events, the more we have to deal with inter-temporal situations with decisions made today and impacts – benefits or damages – in future beyond the timescale of incentives (or pay-outs).

Consequently, any evaluation of a 'risk' of such a decision-making depends on the context, in which an external observes – neither the decision-maker, nor a future beneficiary or damaged party – evaluates what he/she regards as 'risk'. If the context is an optimistic one - '*Rome was a culture that look danger in the eye*' (Beard, 2011) - decisions are made to seize chances and people believe in ingenuity, adaption, and innovations. If the context is a sceptic *Zeitgeist*, people prefer a precautionary principle without solutions, avoid 'risky' decision-making, and believe in planned economies based on blueprints from the past. This antagonism can be found in organisations (i.e. entrepreneurship versus bureaucracy), societies and in a world of global geopolitics with strong externalities. As already Niklas Luhmann (1991) pointed out, there is no ethical benchmark for the one side or the other[50].

[50] Other authors – such as Fabian Schuppert (2017) in: '*Zur Ethik (intergenerationeller) Risikoauferlegung*' - trying to circumvent this problem have to introduce thresholds (to exclude rare, but severe events) and/or focus on the negative impact of decisions (such as energy consumption leading to global warming; see Fig 11.1), but usually exclude the positive effect of e.g. global energy consumption for the development of the global GDP, which is a (of course schematic, but pragmatic) proxy for the development of global wellbeing (see Rosling, 2018),

However, there is a lesson learned that any illusion that we are ‘controlling risk’ does not provide solutions. Maybe an optimistic humility can help to avoid the illusion of risk control, but to be prepared for the future independent of all success in the past – whether in business or in politics.

14. Conclusion

There has been a tremendous development in the concept of '*risk*' from the times of the 'Bankers of Puteoli' to the current proposal of the European Commission regarding credit scoring as a 'high-risk' application': The Roman economy was part of an '*aleatory society',* which regarded 'risk' from a gambling perspective but was capable to provide financial services rather similar to today's financial industry. While the calculus of probability was developed much later in the 17th century/beginning of the 18th century concerning a 'theory of gambling', merchants and merchant banks developed a practice of risk management during the centuries.

The modern understanding of risk management in financial services developed on the basic of 'repeated games' (in the sense of Eugene Fama's efficient markets with a focus on short-term transactions with available liquidity but dropping his assumptions) but – unfortunately – decoupled from the real-world economy of merchants and entrepreneurs involved in long-term projects, which require intertemporal decisions under uncertainty. Consequently, we were educated to define 'risk' with an implicit or (seldom) explicit assumption of 'repeated games'.

Nonetheless, rare but severe 'extreme' events are part of reality, as is the issue of operational resilience for the case that all measures will be unsuccessful and operations have to be restored after disruption will have happened.

Already in the 5th century a Roman writer, Publius Flavius Vegetius Renatus (Vegetius, ca. 450?), formulated the counterfactual[51] approach: '*Igitur qui desiderat pacem, praeparet bellum*' (Therefore who desires peace, prepare for war). This is an antagonistic perspective compared with the Value-at-Risk concept looking at short-term risk within a 95% probability.

Especially commercial decisions often are made on the basis of bounded rationality and in face of completely new challenges without any former experiences. Additionally, 'singular risks' - from the Great Financial Crisis via Climate-Change to Artificial Intelligence (or, at least, the regulatory handling of such technologies) – are always embedded in socio-economical systems.

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[51] Whereas 'counterfactual' does not mean incorrect 'alternative facts' but is a concept of advanced statistics for 'mining worlds that could have been' (see of Pearl, 2018).

The societal understanding or misunderstanding of ‘risks’, the subjective *Katastrophenschwelle*, and a *Zeitgeist der Angst* to made own decisions (but hope for some planned economy) complement a quantitative perspective of risk. This paper is a brief attempt to bridge this gap from ‘repeated games’ to the contemporary socio-economic challenges.

As human beings we prefer linear developments, established rules and predictable situations, whereas we are challenged by non-linear situations or situations about which we have limited strength-of-knowledge. While part of this challenge is a methodological issue (of extreme events), the fundamental questions are the societal awareness for and the political handling of an uncertain future. Maybe this contribution could help to get more insight into ‘*risks beyond repeated games’*.

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Udo Milkau is a 'digital dinosaur' with first experiences in digital technology in 1974, many innovation projects including the first European securities online-brokerage in 1995 and working as a Digital Counselor now. For three decades he holt management positions with automotive industry, professional services firms and transaction banking, served customers in Asia and Europe, the European banking industry, and was Chief Digital Officer, Transaction Banking until 2020. After his academic education in physics, he worked as a research scientist in large collaborations at different European research centres incl. CERN,CEA de Saclay, and GSI.

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