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Science and liability. Exploring the conditions under which mathematicians and other mathematical modellers could be liable

Abstract. In this paper, we examine when mathematicians and other mathematical modellers in similar situations can be held liable in court for knowledge production. We address two fundamental transitions, the secular methodological turn towards generalizations and abstract reasoning that has taken place within mathematics and the sciences, and the "scientification" of policy that has taken place within public governance. Consequently, mathematicians and other producers of abstract knowledge can become subject to liability unawares. We focus on competences, decision making, and risks. To illustrate this new type of liability, we investigate the background of the prosecution of the L'Aquila Seven in the aftermath of the earthquake of 6 April 2009. We try to explain the manifest rejection of any liability from many mathematicians and other scientists working in fundamental research as a "trial against science", regardless whether their work, approaches and behaviour has been (or would be) in one or another way conclusive for the outbreak of a catastrophe or its insufficient mitigation.

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1. Introduction. The Hardy divide has become illusive. From G.H. Hardy we have the famous quote that "a science is said to be useful if its development tends to accentuate the existing inequalities in the distribution of wealth, or more directly promotes the destruction of human life". It was written in 1915, 2 years into the First World War, 9 years before David Hilbert's and Richard Courant's comprehensive treatment of the "methods of mathematical physics" of the time, 14 years after Francis Galton's and Karl Pearson's mathematical advocacy for eugenics, 15 years after Louis Bachelier's *The Theory of Speculation* and 24 years after Carl Häussermann's discovery of the "userfriendly" explosive properties of TNT. Hardy qualified the sentence as "a conscious rhetorical flourish" when he reproduced it 25 years later in[1].

Now, a hundred years later, we see that a substantial part of mathematicians work in fundamental research not pointing to present day applications. In Hardy's view, they keep themselves rather remote from ethical or potentially criminal conflicts as he kept himself

[1] G. H. Hardy, *A Mathematician's Apology* (Cambridge University Press, 1940), n 16.

when working in analytic number theory (e.g., the distribution of prime numbers). Other researchers in sciences and mathematics may act as consultants, e.g., via mathematical modelling. They come close to design tasks or decision making in governments, public agencies, and enterprises with possibly disastrous consequences. In Hardy's view, only these scientists, striving for "useful" results, expose themselves to conditions under which they could be prosecuted. Ironically, already in 1940, when Hardy repeated his sentence, his work in number theory was studied by experts in military cryptology, and some of his results became foundation and tools for high speed encryption and decryption since then.

Hardy's divide was illusive. Since early modern times we have a *fundamental transition* in mathematics and the sciences. Scientific work is less and less determined by objects or segments of the reality investigated, and increasingly by the development of methods and procedures with promises only of future potential uses. This methodological turn has been summarized by Johannes Lenhard and Michael Otte.[2] They were looking for an explanation of the astonishing applicability of abstract mathematical symbols:

> "To Plato and his many followers, mathematics was a science of the unity and order of this universe. Since early modernity, a second answer held that mathematics does not describe the objective world - does not reflect some metaphysical reality - but rather reflects the possibilities of human activity."[3]

With the advances of information technology and model based data gathering and analysis, another *fundamental transition* has taken place within public governance in the last 30 years, with major implications for e.g. mathematicians. Science in general, and modelling in particular, perform a still more important role for public decision making, and accordingly scientists traditionally inhabiting secluded ivory towers, today, find themselves at the heart of public governance – an arena in which mistakes, omissions or plain sloppiness are no longer only moral, but potentially legal wrongs.

Accordingly, today, physicists, mathematicians, and computer professionals may risk criminal or civil prosecution for behaviour that they themselves may consider as purely professional, normal and legitimate. This is no longer a rhetorical flourish. On 22 October 2012, six seismologists and one hydrologist (serving as an administrator) were each convicted to 6 years jail, and banned from ever holding public office again in the judicial aftermath of the L'Aquila earthquake in Central Italy. In November 2014, an appeals court quashed the six seismologists' convictions and reduced the administrator's sentence, a decision later confirmed by the Italian Supreme Court.

Large segments of the international science community condemned the prosecution and the first sentences as a trial against science – and showed relief about the acquittal by the higher courts.[4]

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[2] Johannes Lenhard and Michael Otte, 'The applicability of mathematics as a philosophical problem: Mathematization as exploration' [2018] Foundations of Science 1, 1-19 <https://doi.org/10.1007/s10699-018-9546-2>

[3] Ibid.

[4]See American Association for the Advancement of Science Open Letter, drafted by Alan I. Leshner, Chief Executive Officer and Executive Publisher, Science, 29 June 2010; European Seismological Commission (ESC) Statement on L'Aquila sentence. *ESC Executive Committee*, 26 October 2012; `Shock and law. The Italian system's contempt for its

It seems to us, though, that neither the condemnation nor the relief are sufficiently well informed. In this article, instead of raising moral claims, we wish to draw the attention of our mathematical colleagues and friends to possible and actually observed consequences of the two preceding fundamental transitions.

2. Professional knowledge and liability. There is nothing new to the fact that individuals with skills face a more rigorous standard of legal liability for negligence, than others: 'With great powers, comes great responsibility' as Spiderman's uncle Ben famously rephrases Voltaire. Thus, within tort as well as penal law, people who know what they are doing must subject themselves to a stricter standard of behaviour in cases of liability.[5] For example, you can as a house owner expect more from the professional carpenter you hired to fix your roof, than if you hired your next-door neighbour, who ordinarily works as an IT-professional. One might say that this stricter standard of liability is inherent in the added legitimacy of possessing professional knowledge, experience or/and education.

This is also the case for individuals with very advanced knowledge-based skills. Engineers and doctors are historically well-known examples of such actors relying on advanced knowledge and performing very complex tasks or assessments with potentially direct consequences for third persons. Accordingly, it is of little or no controversy, that an engineer who, due to a miscalculation or time pressure, causes a bridge to collapse would and should face legal scrutiny for such. This is also the case historically, where engineers have faced liability on numerous occasions for negligent behaviour[6], both within penal and torts law[7]. The same prevails for medical doctors. While the discussion of medical liability is highly controversial, when it comes to assessing the exact limits of this liability[8], no one would claim that medical doctors should never face liability charges. Obviously, a doctor performing eye surgery 'forgetting' that the patient was disconnected from a life-supporting ventilator[9] or drunk should be held liable for the inflictions caused as a result of their gross negligence[10].
The standard of liability in such cases relates to a pre-established duty of care, firmly established in a common idea of prudent, well-informed behaviour – and this duty of care increases with the skills of the injurer.

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scientists is made plain by the guilty verdict in L'Aquila' [2012] Nature International weekly Journal of science <https://www.nature.com/news/shock-and-law-1.11643>

[5] Richard W. Wright, ‚The Standards of Care in Negligence Law', in Owen: „Philosophical Foundations of Tort Law", (Clarendon, Oxford University Press, 1995), p. 257ff.

[6] Bell, (1959), Professional Negligence of Architects and Engineers, 12 *Vand. L. Rev.* 711

[7] Ibid.

[8] See e.g. Judith L. Chervenak, Frank A. Chervenak and Laurence B McCoullough, 'A new approach to professional liability reform: placing obligations of stakeholders ahread of their interests' (2019) 203(3) *American Journal of Obsterics Gynecology* 2013.e1, 2003.e1-7.

[9] See R v Adomako 1995 1 AC 171.

[10] See for examples and overview: R. E. Ferner and S. E McDowell, 'Doctors charged with manslaughter in the course of medical practice' (1998) 99(6) *Journal of the Royal Society of Medicine*, 309-14.

Obviously, all of the examples above are related to professionals with decision making power: it might well be that the examples highlighted all require complex knowledge and preparation (like an eye surgery or a bridge construction), but the smart reader might suggest that the problem rests with the decision maker: after all it is the doctor herself, who performs the surgery, and the engineers who builds the bridge.

This article deals with potential liability for a different kind of knowledge-function one-step further removed from the decision-making processes, so-called symbol processing professionals. Thus, the question is when knowledge production, which creates the foundation or legitimation for others' decisions, can be subject to liability. From a liability point of view however, the only difference between the medical doctor who performs the surgery and the medical professor who invented the procedure is a matter of proofing the causality. If it can be proved that a given procedure was used; that it was the procedure and not the surgeon that killed the patient; and that procedure was developed negligently (i.e. not in accordance with duty of care within the medical profession) – the professor is potentially liable – we shall return below to how this might the case for symbol-processing professionals.

A rough taxonomy of how different kinds of advanced knowledge production (science) relates to potential liability might be drawn up on this basis. It seems to us, that two features or trademarks indicate whether a scientific result is risking liability: (1) how likely the result is to affect behaviour/decision making (applicability) and (2) how much damage it could cause if wrong (damage).

Accordingly, a very rudimentary model of how knowledge production and liability relates, with two axis *applicability* and *impact*, can draw a rough idea of when (wrong, misinformed or misinterpreted) knowledge can give raise to liability issues.

A simple model of how this traditionally would play out could look like this:

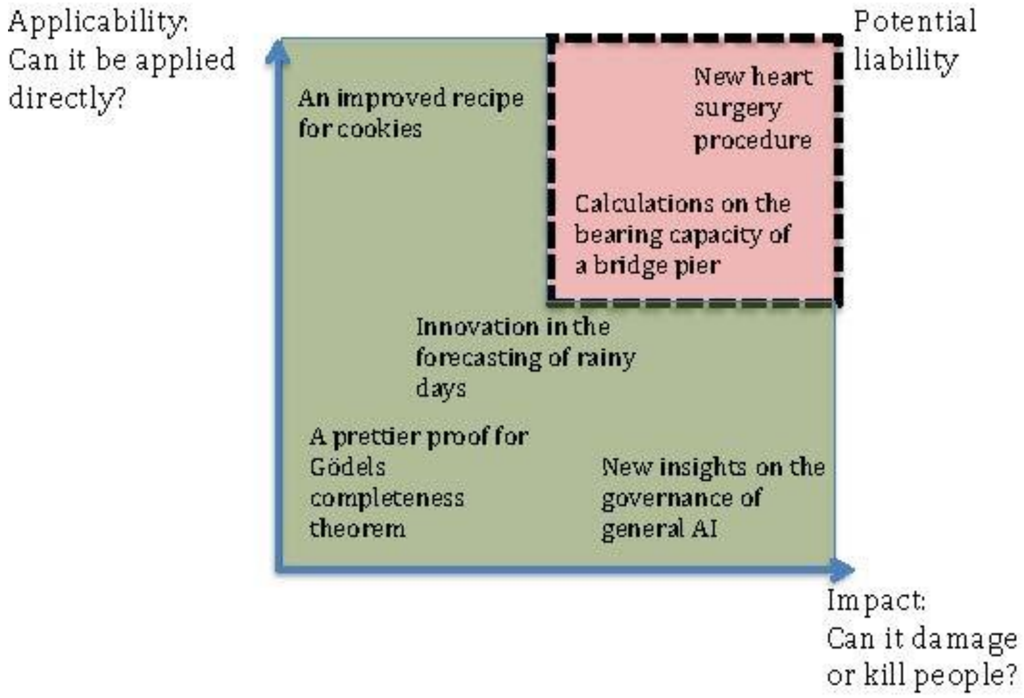

Figure 1: How knowledge production and liability relates (very rudimentary)

Before turning to analyse how these rudimentary concepts might relate to liability of mathematicians, we will first, in some detail, return to Italy and the so-called L'Aquila Seven. The L'Aquila case is interesting because it concerns the core question of this paper, but perhaps even more so, because it is perceived as being entirely central to the question of scientists and liability. It therefore seems crucial to unpack the decision and its context, before exploring the wider question of liability for symbol processing professionals.

3. False parallels. In the international outcry over the 2012 verdict, the criminal court of L'Aquila was compared to the Roman-Catholic courts of the Inquisition and the conviction of the seismologists with the prosecution of Giordano Bruno, Galileo Galilei and many other persecuted famous and innocent physicists and mathematicians.

Indeed, the history of mathematics and physics presents large tables of honour of persecuted scientists. To the best of our knowledge, however, in the past none of the famous prosecuted were prosecuted because of their mathematical or physical research results or claims. We only have evidence of political, religious, racial, sexual or war related prosecution. According to legend, Pythagoras was locked in his home and burnt 510 BCE in a local feud. A Roman soldier killed Archimedes 212 BCE when he did not answer the soldier. The body of Hypatia of Alexandria was in 415 cut to pieces by a Christian mob opposed to her Neoplatonism. Giordano Bruno was condemned to die on fire in 1600 not because of his Copernican celestial views but first due to his belief in reincarnation. Neither were Galileo Galilei accused in 1633 and since then kept in house detention due to his planetary observations and calculations but, basically, to his insistence on the existence of a second holy book, the book of nature written by God in the language of mathematics. The public execution of Lavoisier in 1794 for greed and tax fraud was only indirectly related to his seminal research in chemistry that was financed by those gains. In December 1837, the King of Hannover dismissed Wilhelm Eduard Weber, a close collaborator of Carl Friedrich Gauss and one of the Göttingen Seven, from his post at the university for solely political reasons.

As we know, the racial prosecution of mathematicians and physicists culminated in Nazi-Germany 1933-1945 and was supplemented during and after the Second World War by death sentences against supposed or actual spies, Fritz Noether and Matvei Bronstein in the Soviet Union, Julius and Ethel Rosenberg in the U.S.A., Klaus Fuchs in Great Britain. The prosecution of deviant sexual orientation drew Alan Turing to suicide. During the Cold War, refuseniks had to suffer different kinds of hardship, like Andrei Sakharov in the Soviet Union, Dirk Struik and Lee Lorch in the U.S.A., Mordechai Vanunu in Israel.

Hence, the general picture is that the *criminal prosecution of scientists for their professional doing as scientists* has no, or little, precedence in history. Of course, one can argue that Albert Einstein's special and general theory of relativity were in Nazi-Germany officially discriminated as *Jewish Physics* and Edmund Landau's axiomatic approach to the geometry of numbers as *Non-Arian Mathematics*, though without leading to criminal sentences.

4. The L'Aquila case. The city of L'Aquila with its 70.000 inhabitants is the capital city of the Abruzzo region, about 100 km NE of Rome and positioned at 700 metres elevation. For strategic reasons (disregarding seismic records which might have been available already then), the town was founded and designed around 1230 on the command of Frederick II, Holy Roman Emperor and King of Sicily, according to legend out of several already existing villages in the neighbourhood. The medieval town is built on a rocky hillside within the bed of an ancient lake, providing a soil structure that amplifies seismic waves, see Box 1. It sits beautifully in a narrow valley between four mountain peaks above 2.000 metres. Before the earthquake of 6 April 2009, it used to be a major tourist attraction with many jewellery and fur boutiques, with favourable climatic conditions in both summer and winter, and easily reached from Rome.

4.1 "*The Abruzzo is the most seismologically dangerous zone in all of Italy"*. In the words of one of Italy's most respected geophysicists, Enzo Boschi, then-president of Italy's National Institute of Geophysics and Volcanology (INGV) in Rome and belonging to the six seismologists prosecuted. Italy lies in a tectonically complex region. However, the central part of the Apennines has been characterised by simple extensional tectonics (i.e., by processes associated with the stretching of the crust or lithosphere) since the last 5 million years. Plate tectonic theory predicts that the majority of the Earth's tectonic activity takes place at the margins of plates. So, the Apennines' extensional tectonics can be attributed to the African Plate colliding with the Eurasian Plate, with most of the active faults being normal in type and NW-SE trending, see Figures 2 and 3 and Box 1.[11]

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[11] See also Livio Vezzani, Francessca Ghisetti and Andrea Festa, 'Geology and Tectonic Evolution of the Central-Southern Apennines, Italy', [2010] (January) *Geological Society of America, Boulder, Colorado.*

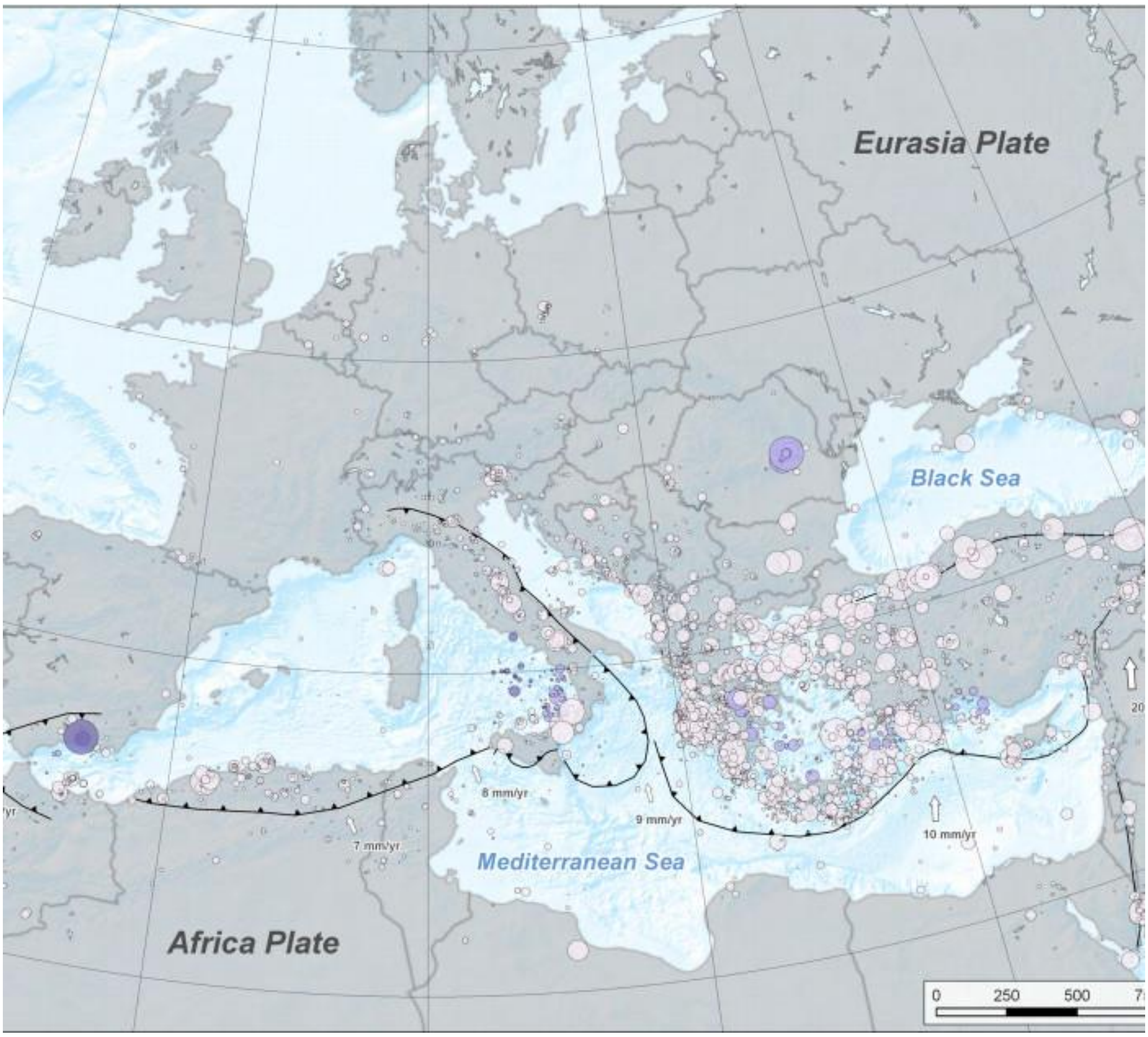

Figure 2. Major earthquakes around the Mediterranean and main faults between the Eurasian and the African Plates, from United States Geological Survey (USGS)

The official Abruzzo portal at http://abruzzo2000.com/abruzzo/laquila/laquila.htm is frank about earthquakes marking the history of L'Aquila with major devastating earthquakes in 1315, 1349, 1452, 1501, 1646, 1703, 1706 and 1958. In view of that historical record, the April 6, 2009 earthquake was no surprise. It was in the relatively small modest-to-strong range of M_W=6.3 on the moment magnitude scale, but with severe consequences. It left 309 dead, 1,500+ injured and 65,000+ homeless.

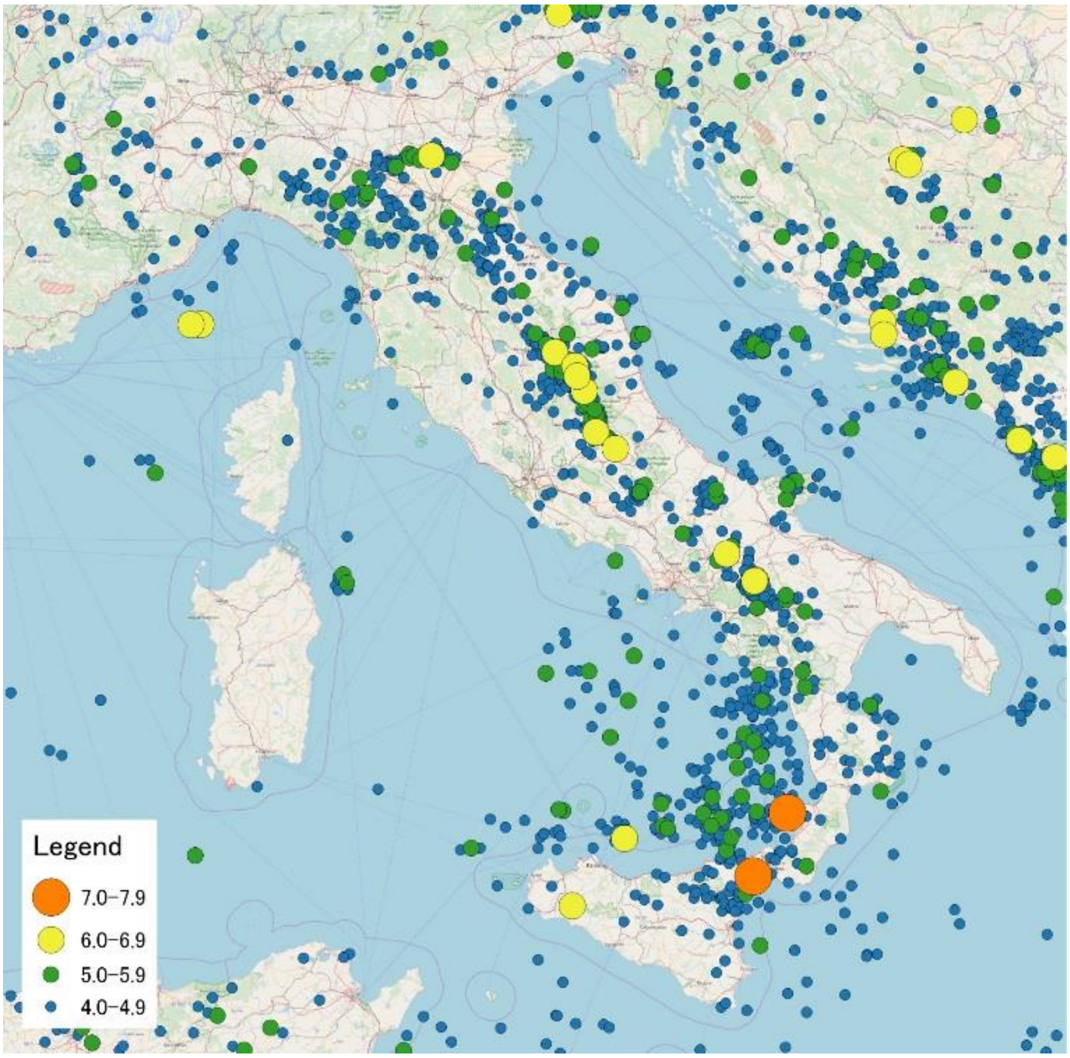

Figure 3. Italian earthquakes 1900-2017, wiki

4.2 *The special meeting on seismic risks of 31 March 2009 and the state of art in earthquake control*. The main shock occurred on April 6 at 03:32 local time. It was embedded in swarms of several thousand foreshocks and aftershocks since December 2008, more than thirty of which had a magnitude greater than M3. The inhabitants of L'Aquila, familiar with the recurrent earthquakes of the region, began to get frightened when frequency and intensity of the shocks increased in the course of March 2009. On March 31, a special meeting was held of Italy's *National Commission for Forecasting and Predicting Great Risks* which was attended by six experts of seismic risks, chaired by the deputy director of the *Italian Civil Protection Agency* (Dipartimento della Protezione Civile), an expert in hydrodynamic engineering. Unanimously the six seismologists declared, that

> (I) reliable short-term prediction of earthquakes is not possible at present, and
>
> (II) the probability of a greater earthquake in the imminent follow-up of the ongoing swarm of minor shocks is very small.

Subsequently, the correctness of Finding (I) was confirmed in declarations by the International Association of Seismology and Physics of the Earth's Interior (IASPEI), endorsed by the European Seismological Commission (ESC) on 26 October 2012[12], supposing a reasonable qualification of the terms *reliable* and *short-term*.
According to the Danish geologist Trine Dahl Jensen,[13] Finding (II) with the term *very small* is sufficiently vague to avoid any falsification.

4.3 *Science and liability. The closer circumstances of the meeting of 31 March 2009*. As mentioned above, the criminal court in L'Aquila showed no doubt that the findings (I) and (II) of the commission meeting of 31 March 2009 were correct within the expressed vagueness. Nevertheless, details about the closer circumstances of the meeting have played a central role for the severe sentences of the criminal court against the seven outstanding scientists for involuntary manslaughter in 29 cases. We restrict ourselves to mention the following circumstances. To us, they continue to seem strange and to cast a bleak shadow on the moral integrity of these persons for their conscious participation in a deliberate game of misleading the public in L'Aquila – in spite of the correctness of the findings of the official meeting and the higher courts' acquittal of six of them later.

1. Normally, meetings of the National Risks Commission are held in Rome. The meeting of March 31 was convened to L'Aquila, and there exist various indications (testimonies, wire tapes) that its purpose was to tranquillize the local population.
2. Normally, meetings of the experts of seismic risks of the National Risks Commission were closed meetings with a joint communique release after the meeting. The meeting of March 31, however, was attended by a broad range of local and regional officials. The officials took care to communicate the results of the meeting (or what they get out of the meeting) to the relevant bodies of administration and the public. They side-lined and silenced the experts.
3. In the presence of one of the experts of the seismic risks, the deputy director of the commission, who had chaired the meeting, held a press conference to explain that the danger was over, that one can safely expect that the swarm of small shocks had reduced the tension between the plates, and the best thing was to relax. On TV he later recommended to find one's preferred chair and open a bottle of Montepulciano, the local red wine.[14]
4. After the end of the meeting and in the following days, the experts declined questions from journalists, thereby indicating that all the necessary was said by the deputy director. During the criminal investigation, wiretapes came forward that proved that the Head of the National Risks Commission (who was not present at the meeting) had urged the experts to leave the public communication to the deputy director to avoid confusion and misunderstandings.

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[12] European Seismological Commission above n 2; *IASPEI Statement on the L'Aquila sentence* (IASPEI Newsletter, November 2012), 1-2.
[13] Trine Dahl-Jensen 'Basic seismic findings regarding the 2009 L'Aquila earthquake'. *Oral presentation, Roskilde University*, 24 November 2017 (not verified).
[14] **Bernado De Bernardinis,** Interview, L'Aquila, 31 March 2009, https://www.youtube.com/watch?v=kLIMHe0NnW8, retrieved 26 January, 2018.

5. The minutes of the meeting were fabricated on April 6, after the disastrous earthquake had happened the same day. The minutes show that the meeting was unusually short, only 60 minutes. It was dominated by local representatives asking the seismic experts to confirm that measured temporarily enlarged radon concentration could not be taken as an indication of an immediate threat of a larger earthquake, against amateurish and outdated belief. During the meeting apparently there were no time or no will to address the particularly high seismic risks of the L'Aquila region, to reaffirm the standard rules of self-protection by leaving the houses, and to communicate which structures should be considered as exceedingly exposed and dangerous.

The combination of these five strange circumstances led the criminal prosecution to charge the seven scientists for manslaughter in the case of 29 named persons. For these persons, the prosecutors could prove that they had packed to leave the town, but died under their houses after they had decided to stay under the impression of the tranquilizing misinformation by the deputy director of the Commission, which was at that time not refuted by the six seismologists.

Roughly speaking, the six seismologists' defence was built along the following lines:
a) They as experts had never been in doubt about the exceedingly dangerous seismic position of L'Aquila and the (always) imminent threat of disastrous earthquakes in that region.
b) They as experts could never have shared the almost imbecile claim of the deputy director regarding the asserted reduction of the seismic tensions by swarms of small shocks. The energy release of earthquakes of magnitude *n+1* is about 32 times the energy release of earthquakes of magnitude *n*. So, only a swarm of more than thousands M4 earthquakes, 2**15 ~ 30.000 M3 earthquakes or a swarm of about 1 million M2 shocks would have been able to remove the tension that led to the disastrous April 6 M 6,3 earthquake.
c) Only long after the meeting of March 31 they became aware, that they were used deliberately to tranquillize the local population, to prevent the mass flight of the population, and to lower the pressure to evacuate (with the economic risks of looting and later claims of damages).
d) As scientists, they were utilized to legitimize a misleading or directly false presentation of scientific arguments in the media. To correct all wrong seismologic mass media information would just physically not be compatible with doing also research.
e) Moreover, their superiors had explicitly forbidden them any personal statements to journalists.
f) The administrators had used them as scapegoats, when in reality house construction failures and poor building supervision were to be blamed for the disastrous outcome of the earthquake.
g) Finally, indicting scientists who serve on a governmental commission for not correcting any nonsense said about their findings would almost automatically and surely in the end lead most eminent scientists to shut their mouth and to abstain from serving as consultants.

4.4 *The legal base of the sentence of the Tribunal of L'Aquila.* On 22 October 2012, the *Tribunal of L'Aquila* condemned seven members of the *National Commission for the Prediction and Prevention of Major Risks* to six years in prison for manslaughter.[15] The court condemned, that they dismissed the role of scientists in a March 31, 2009 meeting: The meeting was convoked in L'Aquila to provide the population of L'Aquila, which was scared after a continuous series of tremors lasting three months, with serious information on a scientific base. On the contrary, the members of the Commission supported a press campaign launched by the Chief of the National Civil Protection to reassure the population. The grounds delivered on 29 January 2013 (first degree of judgment) were based on the Articles 113, 589, c.1 and 3, and 590 of the Italian Criminal Code (113 – Cooperation in negligent homicide, 589 – Negligent homicide, 590 – Negligent personal injury).[16]

So, the local criminal court found a culpability in the behaviour of the deputy director and in the silence of the six seismologists due to advertent negligence (*luxuria*) and causality at least in 29 documented deaths.

The higher Italian courts could not find cogent proof of causality, while they did not comment on the negligence. Without here going in the details of the Italian judicial system or comparing here with other national or international legal basis, right, and practice, to us very strong arguments remain for the culpability of the prosecuted scientists. Within the judicial system in Italy and elsewhere, the range of discretion is narrower regarding the interpretation of the rules than of the facts. Hence, the final outcome could have been equally well a full confirmation of the six seismologists' conviction.

Moreover, it is a strange and provoking fact that apparently there is no acknowledgement of the six seismologists' faults and guilt in the geophysics literature. Against our colleagues and friends it might be worth to recall Richard Feynman's admonition after the loss of the space shuttle Challenger:

> "NASA owes it to the citizens from whom it asks support to be frank, honest, and informative, so these citizens can make the wisest decisions for the use of their limited resources... Reality must take precedence over public relations, because nature cannot be fooled."[17]

Differently put:

> "The L'Aquila order ... is part of the recognition that disasters are increasingly spheres of social control and thereby potential injustice. Disasters form part of a contingent and violent world, but they no longer serve as free get·out·of·jail cards from the responsibility of professional neglect."[18]

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[15] See Case n. 380, *Victims of the earthquake v. Barberi et al.*, (members of the National Commission for the Prediction and Prevention of Major Risks),

[16] Alredo Fioritto, `Science, scientist and judges: Can judges try science?' (2014) 5(2) *European Jounal of Risk Regulation* 133, 133-6

[17] Richard Feynman, `An outsider's inside view of the Challenger inquiry' (1988) 41(2) *Physics Today* 26, 26-40

[18] Kristian Lauta Cedervall, `New fault lines? On responsibility and disasters' (2014) 5(2) *European Journal of Risk Regulation* 137, 137-45. P. 145

5. Politicization of science or 'scientification' of policy? We hope that the criminal prosecution of the six Italian seismologists will serve as a wakeup call exactly because it seems that all six felt fully innocent and the prosecution came as a surprise to them and the whole science community. Actually, that case is not a speciality of Italian law, though it remains spectacular.

The literature referenced above criticizing the L'Aquila case understand the verdict as emblematic for a (dangerous) politicization or *juridification* of science. Thus, the criticism express worry that this is just another example of law and politics unceasing colonization of all aspects of society. In this light, the case is an example of a potentially problematic development: free scientific thinking and freedom of expression are cornerstones within academia, and these should, obviously, not be impeded by an ambiguous risk of legal liability. To this, we agree.

In our perspective, however, this reading of the verdict is wrong. The L'Aquila case was not a 'trial against science', but a trial against a public earthquake governance system – which has always been, and continuously should be, subject to legal and political accountability. In order to explain why scientists are suddenly involved as part of this scrutiny we have to look for answers elsewhere.

Looking to the general governance literature, a change has occurred over the last 30 years for public governance, as noticed above in Section 1: it seems that politics has increasingly been 'scientifisized'. Today, every political decision made base itself on some element of scientific knowledge. For example, no decision on introducing a new food item is made without solid scientific evidence suggesting that it is safe to consume; similarly, no decision on building standards or zones is made without detailed and concrete assessments of the potential for seismic activity.

The British anthropologist Steve Rayner calls our time the 'age of assessment'. In the age of assessment 'a subtle shift [has occurred] from the idea that science should *inform* policy to the idea that science should *drive* policy. This is particularly the case when it comes to *risk governance*. Michael Power already in the 90's asserted that a 'Risk management of Everything'[19] was going on, suggesting that risk was becoming 'an organizing concept as never before'[20]. In the words of Rayner:

'as government shifts towards governance, its policy discourse is increasingly reduced to a discourse of science which, in its turn, is reduced to one of risk.'[21]

Pursuing this claim, the scientists in L'Aquila were not attacked for being scientists nor for being unable to predict earthquakes. In fact, these aspects are only background noise. They stand accused for lending their legitimacy to a political, legal system, without ensuring that the information that drove the policy was correct. Thus, in a closer analogue

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[19] Michael Power, 'The Risk Management of Everything. Rethinking the politics of uncertainty' [2004] *Demos*
[20] Ibid: 13.
[21] Steve Rayner, 'The Rise of Risk and the Decline of Politics' (2007) 7(2), *Environmental Hazards* 165, 165-72, p. 167

as public officials with a mandated function (to provide accurate, state-of-the-art knowledge to the response system).

Obviously, this shift in governance strategy has major implications for accountability. While purely political decisions are ('only') subjected to political sanctions (failing to be re-elected), the type of 'technocratic' decisions outlined above are subject to legal sanctions. If a scientist lends her scientific authority, to legitimize a political decision, it must only be fair that this authority is also accountable for mistakes or negligence (after all, that is exactly it has a valuable authority for the politician). In fact, returning to Power, the drive towards the risk management of everything might be "guided by cultural demands for control, accountability and responsibility attribution"[22].

In this light, we should not understand L'Aquila as an attack on free science or as a positivist assertion of scientific predictions and models. However, it is emblematic to show how the role of (parts of) science has changed in public governance, and thereby offer valuable lessons for scientists across disciplines for how they "lend" their legitimacy, and ultimately accountability, to political processes.

Returning to crude typology for knowledge developed above, mathematicians and other scientists, who previously produced pure symbols, are now supplying evidence-base for public governance systems across the globe. Accordingly, mathematical knowledge in terms of applicability and potential impact moves towards the red square in the top right corner in Figure 1 – making it crucial for mathematicians to openly discuss and critically engage with their role as public scientific advisors or as knowledge providers.

In the following, we will draw up a few examples of how that could be relevant within mathematics.

6. Liability of mathematicians in hypothetical situations evolving from various real cases. To imagine the criminal prosecution of fellow mathematicians might not be as far-fetched as a humorous editorial suggests in the *Mitteilungen der Deutschen Mathematikervereinigung* of December 2012.[23] Roughly speaking we may distinguish three situations where, e.g., mathematicians could be subjected to legal scrutiny, i.e,

- when correct input is utilized in an erroneous way;
- when erroneous input is used in in a correct way; and
- when collecting or providing access to certain data is, on its own, erroneous or a violation of law.

In order to illustrate the relevance of these three situations, we will in the following draw out some cases derived from real recent research projects of colleagues and friends – and hypothetical turns that could have brought them under scrutiny for criminal prosecution.

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[22] Micheal Power, 'The Risk Management of Everything. Rethinking the politics of uncertainty' [2004] *Demos, p. 38*
[23] Martin Skutella,`Editorial' (2012) 20(4) *Mitteilungen der Deutschen Mathematiker-Vereinigung* 193

Presumably, there are hundreds of similar cases in mathematical consulting with real, non-hypothetical pernicious turns that could have brought colleagues in jail, but never did come into the public.

6.1. Correct input utilized in an erroneous way.

Bitumen research. A distinguished group of researchers of a university is collaborating with a multinational street building company and the national street and energy state authorities. The goal is to reduce the rolling resistance of tires on suitably modified bitumen to save energy. Of course, there is the side condition to keep the sliding friction above the formal requirements for braking distances.
The research is done in three subgroups, one of experts in mathematical physics for the theory, one of experts in experimental physics and physical chemistry to conduct the laboratory experiments, and a third group in numerical analysis and data analysis to try digital simulations by molecular dynamics and alternatively by Monte Carlo simulation. The research, including scholarships for two PhD students and the salary for one Post Doc, runs over three years and is financed by funds from the company, the state authorities, and the university, in equal three parts.

Imagine that, just in time, a short while before the project should be terminated, the simulation group could confirm that a certain alternative bitumen blend (and not more expansive than standard bitumen in fabrication and use per application area) should yield an energy saving of up to 5% especially at high velocities. The digital simulation results could neither be reproduced in laboratory experiments nor fully explained theoretically. Anyway, they received a prominent place in the final report, which the project's chief scientist could deliver with some pride.

Both the Department of Energy, one year before elections, and the multinational construction company pushed forward, so that the state street authority approved a 30 km test implementation on a 130 km/h section of a motorway on the countryside. Due to the enthusiasm of the construction company and the Department of Energy (their generous sponsors), the research team did not voice concerns as the limitations of their findings when re-consulted prior to the implementation of the test. Unfortunately, on a rainy day, a defect big truck came to block part of the road. That trivial accident induced a chain car crash with 5 people killed and 42 injured (partly severely). Road police measured strangely long braking marks.

Like shown in L'Aquila, responsibility for research does not end with the publication of a report. It is not unimaginable, that a PI's or main author's imprudent promotion of a given finding could lead to liability in particular, if the research team when re-consulted before the test implementation said nothing. Like in L'Aquila, the researchers would have to justify why they did not raise objections, knowing that their finding had limited validity for the test implementation.

6.2. Erroneous input used in a correct way.

Regulated exocytosis of pancreatic beta-cells and application of an electromagnetic field generator in clinical test. The worldwide epidemic of diabetes type 2 (DT2) raises a variety of mathematical challenges, ranging from the production of insulin vesicles in the pancreatic beta-cells, over the correct secretion of the insulin (regulated exocytosis), to its uptake in muscle tissue when needed. E.g., it has been known for years that many DT2 patients do not suffer from insufficient insulin production within the beta-cells, but from failures of the exocytosis. How can these failures be explained and what kind of remedies can be found?

To answer these two questions, traditionally one assumes that the cell membrane (also called cytoplasmic membrane) controls the movement of substances in and out of cells and organelles. Hence, mainstream research explores the lipid bilayer and the embedded proteins that make the membrane and investigate the ion transport through the membrane and the electrostatic results, which can be measured directly by standard laboratory equipment.

Now an international research network of chemists, cell biologists, experimental physicists, medical doctors, electrical engineers, and mathematicians worked in a different direction, namely on the electrodynamic effects of the observed torrents of ion exchanges between organelles within the cell and the induced low frequent magnetic fields that become closed via the cytoplasmic membrane. Solving Maxwell's equations in that peculiar setting gave the hint, that the electromagnetic effect might be decisive for the functioning of the regulated exocytosis and that "tired" beta-cells could be stimulated to restart the insulin secretion by an electrodynamic generator of pulsating magnetic fields. Experimental set-up with suitably coated nanoparticles confirmed the hypothesis, so that the control experiments could be continued with cell families in vitro and then in test mice.

Imagined: The tests fully confirmed the mathematically found hypothesis, so that the beginning of clinical tests on DT2 patients was permitted by the health authorities, now with up-scaled "bed-side" field generators. To avoid overheating of the tissue, the magnetic field strength was kept at 1 Tesla (a quarter of the magnetic field strength admitted in MRI) and given with low-frequent pulses. The clinical tests had to be halted though already after one week because the associated ionization had induced spread cell necrosis (inflammations) with all patients of such extension that the macrophages could not remove the damaged cells fast enough. The result were strong pain and the generation of up to 1 kg pus in stomach and gut of some patients.

Rather than scrutinizing the external *processes* of dissemination and implementation of scientific findings, the question here is on the validity of the scientific processes themselves, the *internal* scientific processes. That is, potential legal scrutiny would be an investigation of whether the scientists in arriving at the findings followed a commonly agreed-upon scientific duty of care. Obviously, if the research team did so, there can be no liability (as they have no fault).

6.3 Collecting or providing access to certain data, erroneous on its own merits, or as a violation of law.
At an institute of technology, an excellent young professor in mathematical physics was strongly interested in the geometry of and the analysis on graphs. In discussions with a sociologist of a neighbouring university, it became clear, that social sciences were interested and relatively good in detecting communities and identifying and describing social networks between them.

However, social systems are in a constant state of flux, while it seemed that little was known about the regularities governing the microdynamics of social networks. So, the neighbouring university sponsored 3000 smartphones that were distributed to all study beginners at the institute of technology who allowed the tracking of their location day and night for one year under the condition of anonymization. The results were overwhelming in a positive sense: the abundance of data rendered fundamental structures of dynamic social networks. It led to the identification of cores and communities quasi automatically and provided deep insight in human mobility in that age group.

To give all interested sociologists the chance to "play" with that powerful set of behavioural data, the sociologist friend suggested to put a subset of one month data in the anonymized form on the internet.

Imagined: And the young professor did it. It did not take long until an anonymous group of criminals were able to deliver a profile of each of the 3,000 students involved, since a few data points with the given high time resolution sufficed to identify a person. The group tried to press money out of the students by threatening with proliferation of the profiles, but stayed anonymous. Only the young professor was subjected to scrutiny due to a severe break of data protection laws.

7. Ethical controversies. *Moral and science*. We still have to explain the harsh rejection of any legal responsibility common among mathematicians and other scientists working in rather abstract fundamental research, like the L'Aquila seismologists – and most mathematicians and physicists we have talked with.

Getting back to Hardy, there is a long thread of ethical considerations and controversies within mathematics and physics, though previously without judicial consequences.

7.1 The role model is the Hippocratic Oath in medicine. It seems that similar initiatives in biology, chemistry, engineering, and economics could have been wanted in view of the ever increasing social impact of research in these fields (e.g., related to health hazards, toxicity, risks, and social degrading), but apparently have never realized.

7.2 The Wiener model of responsibility and consciousness v. the von Neumann model.
Then there is the individual feeling of guilt or its absence. Under the impression of the

mass extermination of the population of two whole Japanese cities by the atomic bomb, Norbert Wiener wrote an abdication letter to the president of the Massachusetts Institute of Technology (M.I.T.). He announced, later repeated by Wiener on several occasions, that he could not continue further mathematical work at M.I.T. when he should be afraid that "it may do damage in the hands of irresponsible militarists." Actually, he did not send the letter; but that does not matter here.[24]

The opposite position was taken by John von Neumann. According to recollections by von Neumann's friend Stanislaw Ulam, they both joked about Robert Oppenheimer's pronouncement of responsibility and guilt and compared it with a guest at a dinner table who takes the best and largest pieces from a serving without restraint.[25]

We may have more sympathy with Wiener's position, but should recognize that von Neumann's pretended modesty is better founded. Wiener had only very indirectly contributed to the development of the atomic bomb:

- partly by his famous paper with Eberhard Hopf on the radiation equilibrium at the surface of stars and founding the theory of Wiener-Hopf operators which became decisive for solving large classes of boundary value problems,[26]
- partly by his substantial and influential works in Fourier analysis and in probability and control theory.

All these works were important but negligible, perhaps even dispensable compared with the enormous costs and the engineering and design challenges of the construction of the bomb.

Contrary to Wiener, von Neumann was much closer to the Manhattan Project of the fission bomb and played, jointly with Ulam, certainly a decisive role for the development of the fusion bomb, but again a very little role compared to the other tasks. We shall not judge here.

7.3 Why do many mathematicians and other scientists feel a priori innocent and above suspicion? In 1905, Henri Poincaré claimed that morality and science could not be in conflict, for both aimed at the betterment of mankind. We quote from [Poi05, p. 12]: "In the first place (scientific truth) can not conflict with ethics. Ethics and science have their own domains, which touch but do not interpenetrate. The one shows us to what goal we should aspire, the other, given the goal, teaches us how to attain it. So they can never conflict since they can never meet. There can no more be immoral science than there can be scientific morals." From a formal and structural point of view, Poincaré's distinction between the descriptive level (the realm of the sciences) and the normative level (the realm of morality) is highly satisfactory for both mathematicians and jurists. It was

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[24] Heims, Steve J. John von Neumann and Norbert Wiener: From Mathematics to the Technologies of Life and Death. *The MIT Press, Cambridge, Mass*., 1982, 568 pages.
[25] S. M. Ulam, *Adventures of a Mathematician. Charles Scribner's Sons* (University of California Press, 1991) xxxiv+329, p. 170f
[26] Norbert Wiener and Eberhard Hopf, `Über eine Klasse singulärer Integralgleichungen´ [1931] (30-32) *Sitzungsberichte der Preussischen Akademie der Wissenschaften, Physikalisch-Mathematische Klasse* 696, 696-706.

reformulated by the strongly positivist Austrian-American law philosopher Hans Kelsen in to the thesis that no 'ought' can be derived from an 'is' (and vice versa).[27]
In the essay *La morale et la science*, published posthumously in 1913, Poincaré sharpens his view even more. For its characteristic clarity, we give the French original:

> "D'autant plus que la passion qui l'inspire, c'est l'amour de la vérité et un tel amour n'est-il pas toute une morale? Y a-t-il rien qu'il importe plus de combattre que le mensonge, parce que c'est un des vices les plus fréquents chez l'homme primitif et l'un des plus dégradants? ...
> ... la science peut être d'une façon indirecte une auxiliaire de la morale; la science largement comprise ne peut que la servir.*"*[28]

Kelsen points to a logical error in Poincaré's argument:

> "At the end of his essay, (Poincaré) comes to the conclusion that 'science can be indirectly a helpmate of morality; science in the broad sense cannot but serve morality'. His justification for this function of science is the claim that a man of science is filled with love for the truth. 'The passion which inspires him is love for the truth, and is not such a love a morality in itself? Is there anything which needs to be opposed more than lying, because it is one of the most common vices among primitive peoples and one of the most degrading?'.
> But the norm against lying is not a norm posited by science, but a norm of morality; it is the norm which forbids conscious untruth. And a man of science stands in the same relation to this norm as anyone else. Within science, truth-value is not a moral but a logical value, in so far as the truth of statements can be called a 'value' at all, i.e. something commanded (that is, in so far as the logical principle that only one of two contradictory statements can be true can be understood as the command — the norm — that one ought to make only true statements). Morality does not command truth, but truthfulness. *The opposite of scientific — i.e. logical — truth is error, and this is not the same as the opposite of moral truthfulness, i.e. lying*." (emphasis add)[29]

Admittedly things had changed since then.

8. Conclusion. The argument of this paper will be controversial to some readers. It therefore seems none the less important to underline that it is not a prescriptive, but a descriptive claim. This paper is not suggesting that mathematicians *should* be liable, but

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[27] Hans Kelsen `Poincaré's conception of the relation between science and morality´, in: Hans Kelsen, General Theory of Norms. *Oxford University Press*, 1991/2012. German original, posthumous: Allgemeine Theorie der Normen. Edited by K. Ringhofer und R. Walter, *Manz Verlag, Wien*, 1979, Chapter 21.

[28] Poincaré, Henri `La morale et la science'. In: Dernières pensées. *Ernest Flammarion, Paris*, 1913, Chapitre VIII, pp. 223-247. Reprinted 1920 and reproduced at https://fr.wikisource.org/wiki/Dernières_pensées/Texte_entier. Also: Mathematics and Science: last essays. Translated from the French by J. W. Bolduc. Zbl 0121.00102
New York: Dover Publications, Inc. 196, p. 230 and p. 247

[29] Hans Kelsen `Poincaré's conception of the relation between science and morality´, in: Hans Kelsen, General Theory of Norms. *Oxford University Press*, 1991/2012. German original, posthumous: Allgemeine Theorie der Normen. Edited by K. Ringhofer und R. Walter, *Manz Verlag, Wien*, 1979, Chapter 21.

that they *are* subject to such increasingly. The issue does not disappear by ignoring it. We have suggested that this change in the relationship between law and science is not due to changes in the jurisprudence. Rather it is a result of sciences' increasingly important role for policy and public decision-making. In other words, it is not law that has colonized science, but vice versa. While the decision from L'Aquila remains spectacular it is neither unsound, nor atypical for the kinds of cases we will see many more off in the future – including against what we chosen to describe as symbol processing professionals – hereunder mathematicians. To illustrate this, we have suggested three arch type situations in which liability might be a relevant consideration to ongoing or past research projects, involving mathematicians. We hope this will never be relevant.

Appendix. Earthquakes from a mathematical point of view. From a rigorous mathematical point of view, a few comments and a greater precision may be in place regarding the character of the used concepts of "prediction" in Finding (I) and of "probability" in Finding (II) in the statements of the commission cited above in Section 4.2:

Earthquakes like any other disaster raise three fundamental questions:
1. Are earthquakes inevitable?
2. Can we predict earthquakes?
3. Which knowledge and means do we have to mitigate earthquake hazards?

A short answer was given when the Californian seismologist Lucy Jones famously said, "Earthquakes are inevitable, but disasters are not."[30]
Let us say a bit more.

Ad 1. Are earthquakes inevitable? In 1963, Physicist Richard Feynman summarized the general wisdom about the interior of the earth in the following way:

> "A very interesting example of sound waves in a solid, both longitudinal and transverse, are the waves that are in the solid earth. Who makes the noises we do not know, but inside the earth, from time to time, there are earthquakes -- some rock slides past some other rock. That is like a little noise. So waves like sound waves start out from such a source very much longer in wavelength than one usually considers in sound waves, but still they are sound waves, and they travel around in the earth. The earth is not homogeneous, however, and the properties of pressure, density, compressibility, and so on, change with depth, and therefore the speed varies with depth. Then the waves do not travel in straight lines -- there is a kind of index of refraction and they go in curves. The longitudinal waves and the transverse waves have different speeds, so there are different solutions for the different speeds...
>
> The only way we know what is inside the earth is by studying earthquakes. So, by using a large number of observations of many earthquakes at different stations, the details have been worked out -- the speed, the curves, etc. are all known. We know what the speeds of various kinds of waves are at every depth. Knowing that, therefore, it is possible to figure out what the normal modes of the earth are."[31]

With hindsight, Feynman's enthusiasm of 1963 is understandable: Exactly that progress in catching and analysing seismic waves, as described by Feynman, was a decisive step on the long way to the Threshold Test Ban Treaty of 1974 and the Comprehensive Nuclear-Test-Ban Treaty of 1996, both relying on national means for verification. However, the

[30] [Jon16]
[31] [Fey63, Vol. 1, Section 51-3 on Waves in solids]

promises of a full understanding of the normal modes of the earth and of the ways how some rock slides past some other rock have been in vain so far.

The seismologists Seth Stein and Michael Wysession provide in[32] a simple mathematical explanation: They distinguish between the kinetics and the dynamics of underground events. Questions of *kinetics* are typically ex-post explorations about the time, the site, the character (natural v. artificial) and the magnitude of an event and eventually the direction of induced faults. They are purely descriptive. Questions of *dynamics* are elucidative. They address the physics of the event, i.e., the details of the underlying process and its build-up – and so chances of an artificial halt by suitable means of human interference. In both cases, analysing seismic waves to answer the questions is, mathematically, an inverse problem. The simple mathematical fact is, that the inverse problems raised by kinetic questions are related to rather well-posed problems, while the inverse problems raised by dynamical questions typically are related to strongly ill-posed problems where only vague and ambiguous information can be regained.

Perhaps we should be glad that Stein and Wysession's argument has brought the adventurous plans by E. Teller and other promotors of "new applications for hydrogen bombs" to an end.[33] We had better not see nuclear bombs as "giant shovels" or "huge nutcrackers" for counteracting and discontinuing an evolving earthquake, even a hydrogen bomb of 6 megatons TNT equivalent has an energy release on the same scale as an earthquake of magnitude M8.

To describe the scientific challenges of understanding the cause of earthquakes and other disasters, Stein quotes from military policy a qualification of the Socratic "οἶδα οὐκ εἰδώς - I know that I do not know" in three directions: "There are known knowns. These are things we know that we know. There are known unknowns. That is to say, there are things that we know we don't know. But there are also unknown unknowns. There are things we don't know we don't know."[34]

For understanding the true physics of what causes an earthquake, Stein's conclusion is that we should both use what we know and keep learning more. In 2010, Stein put his hopes in particular on large arrays of distributed seismographs and on spaceborne data of ever better quality provided by the well-established Global Positioning System (GPS) and the emerging technique of Interferometric Synthetic Aperture Radar (InSAR) used in geodesy and remote sensing. To InSAR,[35] in particular the review[36] based on the enthusiastic working paper.[37] The latest version of the European Space Agency's Observing the Earth. The Living Planet Programme, however, does not any longer contains any reference to seismology exploration.[38]

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32 [Ste91, Chapter 7 on Inverse problems]
33 [Tel 96]
34 [Stei10, p. 253]
35 see also [Fre10]
36 [Lau10]
37 [ESA07]
38 [ESA17]

Ad 2. Can we predict earthquakes? In relation to earthquakes, one must distinguish between forecasts and predictions. [Jon96] Forecasts give long-term estimates on seismic hazards for a chosen region based on historical records for that region or records for comparable regions. E.g., having observed that a given region averages two quakes above M5 every year, we can estimate that the annual probability of such an event is between 80-90%, depending on whether we model the chance events by a Poisson distribution or another distribution which does not exclude clustering. Such forecasts carry a high uncertainty, due to the low quality and quantity of the data and to the uncertainty about the chosen stochastic model.[39] They can be useful, though, for allocating funds to civil protection measures[40] – or for the setting of insurance rates.[41]

Predictions in the narrow sense seek beyond achieving a random distribution. They wish to give a timely alarm by predicting the time, site, and magnitude of a greater seismic event. As the Islandic geophysicist Ragnar Stefánsson put it at the very beginning of his 2011-monograph on Advances in Earthquake Prediction: Research and Risk Mitigation: "Since the beginning of seismology 100 years ago it has been the hope of seismologists to be able to predict earthquakes in order to help populations across the globe avoid destruction and casualties. Nonetheless, earthquakes continue to occur without warning."[42]

Actually, parallel to the enormous progress in numerical weather prediction in the 1970-1990, there had been many efforts in geophysics to analyse patterns of underground waves, partly motivated by control tasks of the nuclear test ban, partly with the goal to develop alarm systems for earthquakes.

Early in the morning of February 4, 1975, in the then one-million-inhabitants city of Haicheng in the northeast of China, Chinese officials issued an evacuation order due to an increase in foreshocks. The evacuation came just in time before a huge M7+ earthquake in the evening of the same day. The death toll of 2.041 people was much lower than the estimate of over 150.000 dead that is believed to have resulted if the evacuation had not taken place.

Naturally, that success turned special attention to a variety of predictive ideas and approaches in three categories:
(i) some are based on observable emissions of gases, in particular Radon, observable strange behaviour of animals, reported strange dreams, etc;
(ii) some are based on semi-Markov models for multi-precursor systems in a retrospective analysis of seismic swarms; and
(iii) some are based on the early recognition of the main tremor.

None of the approaches of category (i) could be confirmed empirically.

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39 [MiGa89], [GMR90], [Leo08], [[Kag10, 14]
40 HaGa09], [AGL17]
41 [Stei10]
42 [Stef11, p. 1]

Let’s turn to approaches of category (ii), without going in the details of the wide literature on that subject especially in the 1980s-1990s.[43]

The results of a investigation for California[44] and of one for three earthquake-prone Italian localities were conclusive and almost identical.[45] For a single turbulence of magnitude M1 the probability ß was estimated for a second shock of magnitude ≥ M2 within a time interval of Δt and a radius of Δr. E.g., Lucille Jones found, that "the main shock will most likely occur in the first hour after the foreshock, and the probability that a main shock will occur decreases with elapsed time from the occurrence of the possible foreshock by approximately the inverse of time. Thus, the occurrence of an earthquake of M ≥ 3,0 in southern California increases the earthquake hazard within a small space-time window several orders of magnitude above the normal background level.”

A systematic statistical analysis of three Italian regions of high seismic hazards comes to a similar conclusion:

> "it seems that the short-term precursor consisting of potential foreshocks has practically the same characteristics in many different regions, namely a high probability of false alarm (p = ~0.98) and a relatively low probability of missed alarm (q = ~0.5).”[46]

It seems that these results are also valid for the L’Aquila region and can be verified by checking the databases both for all Italian earthquakes in 1900-2017 and for the list of historically registered tremors and earthquakes in the L’Aquila region from 1500 till now. That last list is said to show about 20 earthquakes of >M5, about 500 extensive periods of tremors, but that roughly speaking only ten out of the 20 were immediate followers of a tremor period and so 490 tremor periods out of 500 have not been precursors to larger earthquakes. That would again amount to p = ~0.98 and q = ~0.5. However, we have to make some reservation for a possible lack of reliability of such widespread historical data and the lack of a specification of the observational parameters and the probabilistic model Therefore, we use these figures solely for illustration.

So, rigorously speaking, one can easily imagine a reliable alarm system based on simple registering of potential foreshocks, which would correctly predict half of the major events, but on the costs of more than 90% false alarms. It seems that research in that direction has come to a halt due to the enormous costs of false alarm and the fatigue of the crywolf in the long run. As Michael-Leiba and Gaull put it explicitly in their Probabilistic earthquake risk maps of Tasmania: "The earthquake process was assumed to be Poissonian, so foreshocks and aftershocks were eliminated from the analysis.”[47]

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43 [Agn91], [Gasp92], [Gasp07], [Gra83, 88, 98], [Gua82, 86], [Jon85, 96].
44 [Jon85]
45 [Gra88]
46 [Gra88, p. 1542]
47 [MiGa89]. See Similarly [GMR90].

Costly alarm systems of category (iii) are implemented in Japan, Southern California and Mexico and under construction in other parts of the world. Arrays of sensors can detect strong seismic waves at the very beginning of a major earthquake and provide alarm time of between 20 and 60 seconds. Both administers and seismologists seem divided about the practical success of such systems.[48]

Ad 3. Which knowledge and means do we have to mitigate earthquake hazards? Clearly, the main direction of seismic research of the last decade is directed to mitigate earthquake hazards by integrating different technologies in the stages before, during and after the earthquake. This is called an integrated hazard mitigation system. The Japanese structural engineer Takuji Kobori summarized in:

> "Before an earthquake, it is necessary to carry out a seismic assessment of old structures and to monitor the health of important structures, such as highway bridges. It is necessary to predict social damage. The first early warning system aims at catching the phase just before the arrival of strong ground motions. The second system involves the application of structural control technology and plays an important role in preventing structural damage and in maintaining functional losses of important facilities by reducing strong shaking. The third system comprises post-control immediately after the event." [49]

This approach to earthquake mitigation correlates with a larger reorientation within disaster studies.[50] Rather than approaching disasters from the perspective of the hazard, modern disaster research understand disasters as the result of pre-existing vulnerabilities.[51] Broadly speaking these vulnerabilities cover all 'pre-disaster conditions'[52], or "weakness in social structures or social systems"[53]

In this light, the disaster in L'Aquila was triggered by an earthquake but caused by the pre-configuration of the local community. Thus, it was rooted in the built environment, in the institutional emergency preparedness system (including the knowledge of seismic risks) as well as in the behaviour of the community affected. For a closer examination of the social root causes of L'Aquila, the British disaster sociologist David Alexander offers a closer account.[54]

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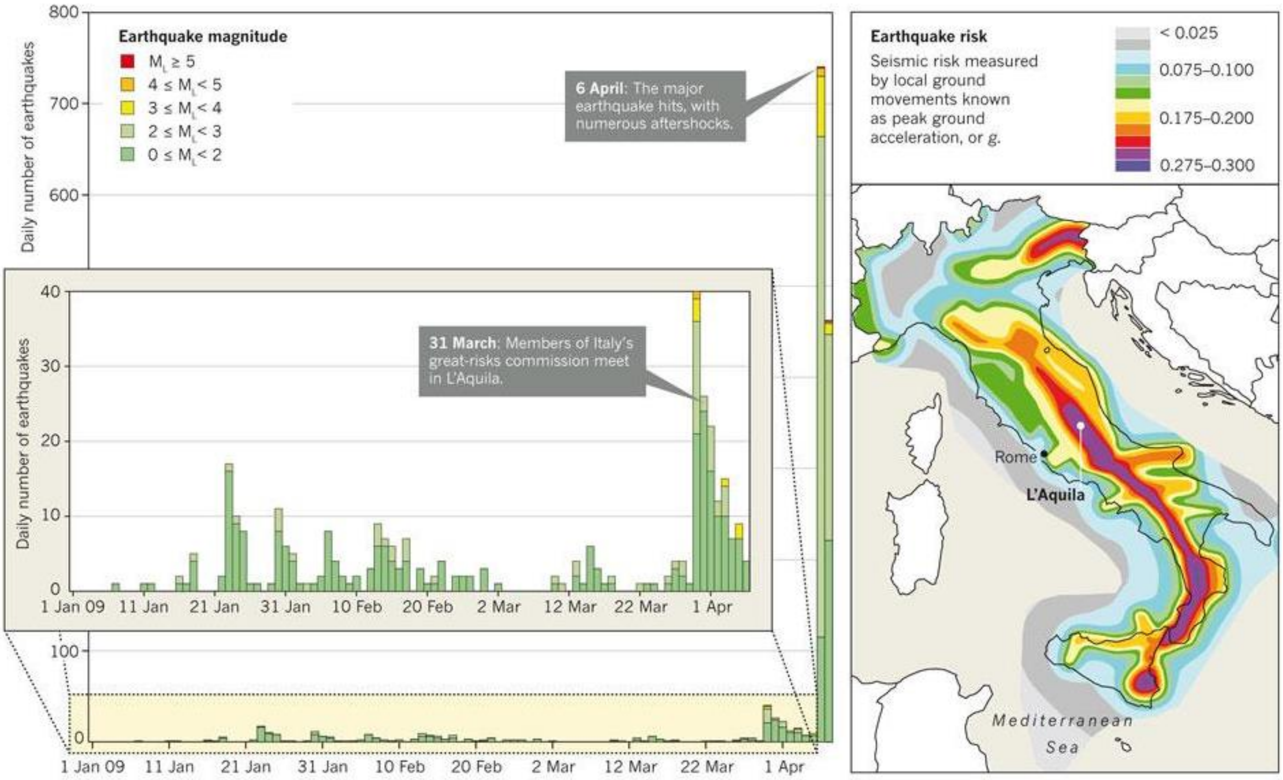
[48] [Stei10], [Wen14]
[49] [Kob99]. See also [Leo08], [HaGa09], [Stef11], [Stei10], [AGL17] and the highly informative interview [Jas16].
[50] [Perr07] (Perry 2007)
[51] [Wisn04] (Wisner et al. 2004)
[52] Oliv99] (Oliver-Smith and Hoffman 1999)
[53] [Perr05] (Perry and Quarantelli 2005).
[54] [Alex14]. (Alexander 2014)



Box 1, Seismic facts and parameters for the 6 April 2009 L'Aquila earthquake

Source: L'Istituto Nazionale di Geofisica e Vulcanologia (INGV), reproduced from [Hal11]. Here, the magnitudes of the precursor tremors are given in the *Richter scale* M_L that measures the total amount of energy released at the source in a logarithmic scale. Around the globe, it can easily be read at any seismograph after correcting for the distance between source and seismograph. The distance is calculable from the difference between the arrival times of surface and body waves at the measuring site or, more precisely and yielding the depth of the hypocenter (*focus*) as well, from the arrival times of seismic waves recorded on seismometers at different sites).

Other scales exist for a better estimation of *local effects* like the impact on surface structures, death toll and other damages, e.g.,the *Moment scale* M_W and the *Peak Ground Acceleration* (*PGA*). The Moment scale of magnitude is closely related to the Richter scale and up to M6 practically identical with it. It measures the amount of energy released in the same logarithmic scale. However, it is "based on the *seismic moment* of the earthquake, which is equal to the *shear modulus* of the rock near the fault multiplied by the average amount of *slip* on the fault and the size of the *area* that slipped" (wiki). The PGA denotes the maximum ground acceleration that occurred during earthquake shaking at a location. It is measured in parts of *g*, the Earth's gravity. For an extensive discussion of these and other parameters, their measuring, and their meaning see Stei13, Section [Bor13].

Local effects have been severe in the L'Aquila earthquake of 6 April 2009, that released a relatively modest amount of energy with M_W=6,3. One explanation is that L'Aquila is built on a dry lakebed with soft sediment soil made up of sand and clay. The loose underground slows the surface waves that major earthquakes cause. By energy conservation, the attenuation of the propagation speed generates heat and enlarges the waves' amplitudes. That amplifies the shaking and amplifies the destruction, according to [Jon17] by a factor of up to 100, more realistically by a factor of 10-20 according to [Vos17]. Purely mathematically, that effect is identical with the well-known breaking of waves and the tsunami effect on flat shores. For a rigorous explanation, see any textbook on wave propagation, e.g., [Stei91], p. 61 in Section 2.4.5 on *Energy in a plane wave*, for horizontally polarized seismic shear waves *SH* with displacement in the *y* direction, parallel to the earth's surface.

References

David Alexander, 'Communicating earthquake risk to the public: the trial of the "L'Aquila Seven"' [2014] *Journal of the International Society for the Prevention and Mitigation of Natural Hazards*

American Association for the Advancement of Science Open Letter, drafted by Alan I. Leshner, Chief Executive Officer and Executive Publisher, *Science*, 29 June 2010.

Abazagic, Belma Die Libor-Manipulationen und ihre Rechtsfolgen, Dissertationsexposé, Wien, June 2016, 19 pages with 7 pages references.

Anita Amirsardari, Helen M. Goldsworthy and Elisa Lumantarna 'Seismic site response analysis leading to revised design response spectra for Australia' (2017) 21(6) *Journal of Earthquake Engineering*, 861-90

Duncan Carr Agnew and Lucile M. Jones, 'Prediction probabilities from foreshocks' (1991) 96 *Journal of Geophysical Research* 11959, 11959-71

Alberta Alemanno and Kristian Cedervall Lauta, 'Editorial. The L'Aquila Seven: re-establishing justice after a natural disaster' [2014] (5-2) *European Journal for Risk Regulation* 129, 129-32

Bell, (1959), Professional Negligence of Architects and Engineers, 12 *Vand. L. Rev.* 711

Bernado De Bernardinis, Interview, L'Aquila, 31 March 2009, https://www.youtube.com/watch?v=kLIMHe0NnW8, retrieved 26 January, 2018.

Peter Bormann, Siegfried Wendt, and Domenico Di Giacomo `Chapter 3: Seismic Sources and Source Parameters'. In: Bormann, New Manual of Seismological Observatory Practice 2 (NMSOP-2), *GFZ German Research Centre for Geosciences, Potsdam*, 2013, doi:10.2312/GFZ.NMSOP-2_ch3

Yousef Bozorgnia and Vitelmo V Brteo, *Earthquake Engineering: From Engineering Seismology to Performance-based Engineering (CRC Press, 2004) xvi-1251*

Judith L. Chervenak, Frank A. Chervenak and Laurence B McCoullough, 'A new approach to professional liability reform: placing obligations of stakeholders ahread of their interests' (2010) 203(3) *American Jounal of Obsterics Gynecology*.e1, 203.e1-7.

Trine Dahl-Jensen 'Basic seismic findings regarding the 2009 L'Aquila earthquake'. *Oral presentation, Roskilde University*, 24 November 2017 (not verified).

European Space Agency `InSAR principles — Guidelines for SAR interferometry processing and interpretation', *ESA TM-19*, 2007.

European Space Agency Observing the Earth. The Living Planet Programme. Last update: 12 June 2017. http://www.esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet_Programme

European Seismological Commission (ESC) Statement on L'Aquila sentence. *ESC Executive Committee,* 26 October 2012.

Alredo Fioritto, `Science, scientist and judges: Can judges try science?' (2014) 5(2) *European Jounal of Risk Regulation* 133, 133-6

R. E. Ferner and S. E McDowell, 'Doctors charged with manslaughter in the course of medical practice' (1998) *Journal of the Royal Society of Medicine 99(6), 309-14*

R. E. Ferner and S. E McDowell, 'Doctors charged with manslaughter in the course of medical practice' (1998) 99(6) *Journal of the Royal Society of Medicine* 309, 309-14

Richard Feymann, Robert B. Leighton and Matthew L. Sands, *The Feynman Lectures on Physics* (Pearson P T R, 1970 1st ed) vol 3.

Richard Feynman, `An outsider's inside view of the Challenger inquiry' (1988) 41(2) *Physics Today* 26, 26-40

Will M. Freeden, Zuhair Nashed and Thomas Sonar (eds), *Handbook of Geomathematics* (Springer, 2010) vol 1.

Gasparini et al (eds), *Volcanic Seismology* (Springer, 1992) xviii-572

Gasparini et al (eds.) Earthquake Early Warning Systems. *Springer, Berlin-Heidelberg,* 2007, ISBN 3540722416, 9783540722410, xxiv+349 pages.

Brian A. Gaull, Marion O. Micheal-Leiba and J. M. W. Rynn, `Probabilistic earthquake risk maps of Australia' (1990) 37(2) *Australian Journal of Earth Sciences 169, 169-87*

Elisa Guagenti Grandori and Giuseppe Grandori, `Some probabilistic aspects of earthquake prediction´ (1983) 18 *Meccanica, the official journal of the Italian Association of Theoretical and Applied Mechanics* 246, 246-53

Elisa Guagenti Grandori and Federica Perotti, `Alarm systems based on a pair of short-term earthquake precursors' (1988) 78(4) *Bulletin of the Seismological Society of America 1538, 1538-49*

Elisa Guagenti Grandori and Aldo Tagliani, 'Seismic hazard analysis: how to measure uncertainty? (1998) 67(1-3) *Computers & Structures* 47, 47-51

Elisa Guagenti Grandori, 'Stochastic models of seismic risk reduction' (1982) 52 *Seminario Matematico e Fisico di Milano* 283, 283-97.

Elisa Grandori Guagenti and Chiara Molina `Semi-Markov processes in seismic risk analysis'. In: Semi-Markov Models (Brussels, 1984), pp. 487-503, *Plenum, New York,* 1986; MR0874009.

Stephen S. Hall, `Scientists on trial: At fault? - Nature News', [2011] (September) *Nature 477 264, 264-9*

G. H Hardy, *A Mathematician's Apology* (Cambridge University Press, 1940)

[HaGa09] Hao, Hong, and Brian A. Gaull `Estimation of strong seismic ground motion for engineering use in Perth Western Australia', *Soil Dynamics and Earthquake Engineering* 29 (May 1, 2009), 909-924, Partly announced in the authors' `Prediction of seismic ground motion in Perth Western Australia for engineering application', *Proc. 13th World Conf. Earthquake Eng.*, Vancouver, B.C., Canada, August 1-6, 2004, Paper No. 1892, available at http://www.iitk.ac.in/nicee/wcee/article/13_1892.pdf.

[Hei82] Heims, Steve J. John von Neumann and Norbert Wiener: From Mathematics to the Technologies of Life and Death. *The MIT Press, Cambridge, Mass*., 1982, 568 pages.

[IAS12] International Association of Seismology and Physics of the Earth's Interior (IASPEI) IASPEI Statement on the L'Aquila sentence. *IASPEI Newsletter*, November 2012, p. 1-2. The IASPEI is one of the eight Associations of the International Union of Geodesy and Geophysics (IUGG).

[Jas16] Henry, Jason. `Why Lucy Jones' retirement might just save thousands of lives during earthquakes', *Interview, Pasadena Star-News*, 18 March 2016. http://www.pasadenastarnews.com/science/20160318/why-lucy-jones-retirement-might-just-save-thousandsof-lives-during-earthquakes). Retrieved 7 January 2018.

[Jon85] Lucile M. Jones,`Foreshocks and time-dependent earthquake hazard assessment in southern California' (1985) 75(6) *Bulletin of the Seismological Society of America 1669, 1669-79.*

[Jon96] Lucile M. Jones, `Earthquake prediction: the interaction of public policy and science' (1996) 93, *Proceedings of the National Academy of Sciences of the United States of America 3721, 3721-5.*

[Jon17] Lucile M. Jones, `Why does M7.1 cause so much damage?', https://twitter.com/DrLucyJones/status/910233833231998976, 19 Sept. 2017.

[Kag10] Yan Y. Kagan, `Statistical distributions of earthquake numbers: consequence of branching process' (2010) 180(3) *Geophysical Journal International* 1313, 1313-28.

[Kag14] Yan Y. Kagan, *Earthquakes. Models, Statistics, Testable Forecasts* (Wiley-blackwell, 2014) xxi-281

[Kel79] Hans Kelsen `Poincaré's conception of the relation between science and morality′, in: Hans Kelsen, General Theory of Norms. *Oxford University Press*, 1991/2012. German original, posthumous: Allgemeine Theorie der Normen. Edited by K. Ringhofer und R. Walter*, Manz Verlag, Wien*, 1979, Chapter 21.

[Kob99] Kobori, Takuji `The role of structural control for integrated hazard mitigation systems'. In: Rodellar, J. (ed.) et al., Advances in structural control. *CIMNE, Barcelona*, 1999, pp. 403-426. Zbl 0990.93085

[Lau10] Laur Henri, and Volker Liebig `Earth observation satellite missions and data access'. In: [Fre10], pp. 69-92.

Kristian Lauta Cedervall, `New fault lines? On responsibility and disasters' (2014) 5(2) *European Journal of Risk Regulation* 137, 137-45.

[Leo08] Lenard Mark, `One hundred years of earthquake recording in Australia' (2008) 98 *Bulletin of the Seismological Society of America* 1458, 1458-70.

[LeOt18] Johannes Lenhard and Michael Otte, 'The applicability of mathematics as a philosophical problem: Mathematization as exploration' [2018] *Foundations of Science 1, 1-19 <https://doi.org/10.1007/s10699-018-9546-2>*

[MiGa89] Marion O Michael-Leiba and Brian A. Gaull, `Probabilistic earthquake risk maps of Tasmania' (1989) 11 *Journal of Australian Geology and Geophysics* 82, 82-7.

[Nat12] Note, `Shock and law. The Italian system's contempt for its scientists is made plain by the guilty verdict in L'Aquila' [2012] *Nature International weekly Journal of science <https://www.nature.com/news/shock-and-law-1.11643>*

Anthony Oliver-Smith and Susannah M. Hoffmann (eds), *The Angry Earth: Disaster in Anthropological Perspective* (Routledge, 1999 1st ed) xiii, 334

Ronald W. Perry, *What Is a Disaster?* (Perry, 2007) Quoting/Quoted in/citing/cited in Havidán Rodríguex, Willam Donner, Joseph E. Trainor (eds), *Handbook of Disaster Rescearch* (Springer International Publishing, 2018 2nd ed)

Ronald W. Perry and E.L Quarantelli, *What Is a Disaster* (Philadelphia, Pa.: Xlibris, 2005)

[Poi05] Henri Poincaré, *The Foundations of Science : Science and Hypothesis, The Value of Science, Science and Method* (Geirge Bruce Halsted, New York, 1913) [trans of: Bibliothèque de philosophie scientifique (first published 1905)]

[Poi13] Poincaré, Henri `La morale et la science'. In: Dernières pensées. *Ernest Flammarion, Paris,* 1913, Chapitre VIII, pp. 223-247. Reprinted 1920 and reproduced at https://fr.wikisource.org/wiki/Dernières_pensées/Texte_entier. Also: Mathematics and Science: last essays. Translated from the French by J. W. Bolduc. Zbl 0121.00102
New York: Dover Publications, Inc. 1963. 121 pages.

Michael Power, 'The Risk Management of Everything. Rethinking the politics of uncertainty' [2004] *Demos*

Steve Rayner, 'The Rise of Risk and the Decline of Politics' (2007) 7(2), *Environmental Hazards* 165, 165-72

[Stef11] Stefánsson, Ragnar Advances in Earthquake Prediction: Research and Risk Mitigation. Praxis Books Geophysical Sciences. *Springer, Berlin-Heidelberg,* 2011,
ISBN 3540475710, 9783540475712, xxviii+245 pages.

Ragnar Stefánsson, *Advances in Earthquake Prediction: Research and Risk Mitigation* (Springer-Praxis Book in Geophysical Science, 2011) xxviii-245

[Stei91]
Seth Stein and Michael Wysession, *An Introduction to Seismology, Earthquakes, and Earth Structure* (John Wiley & Sons, 1991) xii-510

[Stei10] Seth Stein, *Disaster Deferred: How New Science is Changing Our View of Earthquake Hazards in the Midwest* (Columbia University Press, 2010) xii-282

[Ula76] S. M. Ulam, *Adventures of a Mathematician. Charles Scribner's Sons* (University of California Press, 1991) xxxiv+329

[Vez09] Livio Vezzani, Francessca Ghisetti and Andrea Festa 'Caratterizzazione strutturale dei principali sistemi di faglie dell'Abruzzo Aquilano' (2009) 28 *Geoitalia* 4, 4-12

[Vez10] Livio Vezzani, Francessca Ghisetti and Andrea Festa, 'Geology and Tectonic Evolution of the Central-Southern Apennines, Italy', [2010] (January) *Geological Society of America, Boulder, Colorado*

[Vos17] Voss, Peter `On basin effects´, email consultation, 21 September 2017.
Email consultation from Peter Voss to XX, 21 September 2017

[Wen14] Wenzel et al (eds), *Early Warning for Geological Disasters: Scientific Methos and Current Practice: Scientific Methods and Current Practice* (Advanved Technologies in Earth Sciences, 2014) xv-379

[Wie31] Norbert Wiener and Eberhard Hopf, `Über eine Klasse singulärer Integralgleichungen´ [1931] (30-32) *Sitzungsberichte der Preussischen Akademie der Wissenschaften, Physikalisch-Mathematische Klasse* 696, 696-706.

Ben Wisner et al, *People's vulnerability and disasters* (Taylor and Francis, 2th ed, 2004)

Wright, Richard W. (1995) ‚The Standards of Care in Negligence Law', in Owen: „Philosophical Foundations of Tort Law", Clarendon, Oxford University Press,