

A Conversation With Paul Embrechts

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Summary

Paul Embrechts was born in Schoten, Belgium, on 3 February 1953. He holds a Licentiaat in Mathematics from Universiteit Antwerpen (1975) and a DSc from Katholieke Universiteit Leuven (1979), where he was also a Research Assistant from 1975 to 1983. He then held a lectureship in Statistics at Imperial College, London (1983–1985) and was a Docent at Limburgs Universitair Centrum, Belgium (1985–1989) before joining ETH Zürich as a Full Professor of Mathematics in 1989, where he remained until his retirement as an Emeritus in 2018. A renowned specialist of extreme-value theory and quantitative risk management, he authored or coauthored nearly 200 scientific papers and five books, including the highly influential ‘Modelling of Extremal Events for Insurance and Finance’ (Springer, 1997) and ‘Quantitative Risk Management: Concepts, Techniques and Tools’ (Princeton University Press, 2005, 2015). He served in numerous editorial capacities, notably as Editor-in-Chief of the *ASTIN Bulletin* (1996–2005). Praised for his natural leadership and exceptional communication skills, he helped to bridge the gap between academia and industry through the foundation of RiskLab Switzerland and his sustained leadership for nearly 20 years. He gave numerous prestigious invited and keynote lectures worldwide and served as a member of the board of, or consultant for, various banks, insurance companies and international regulatory authorities. His work was recognised through several visiting positions, including at the Oxford-Man Institute, and many awards. He is, inter alia, an Elected Fellow of the Institute of Mathematical Statistics (1995) and the American Statistical Association (2014), an Honorary Fellow of the Institute and the Faculty of Actuaries (2000), Honorary Member of the Belgian (2010) and French (2015) Institute of Actuaries and was granted four honorary degrees (University of Waterloo, 2007; Heriot-Watt University, 2011; Université catholique de Louvain, 2012; City, University of London, 2017). The following conversation took place in Paul's office at ETH Zürich, 17–18 December 2018.

Key words: Extreme-value theory; finance; insurance; quantitative risk management.

1 The Beginnings

Johanna: It's good to be back at ETH to discuss your distinguished academic career.

Christian: Could you start by telling us a bit about your childhood and education?

Paul: I came from a very happy but modest working class family from Schoten, near Antwerpen, Belgium. I was the second of three children and the first to go to university. My father was a policeman and my mother stayed home with us. Although there were no academics anywhere in sight, we lived in an ambiance of liberal, academic thinking. My father was very clever; he had a natural knack for numbers and served as a combat engineer during the war. My mother was a very talented writer; she used to compose poems, which she never published

unfortunately. From my early childhood she stressed that I liked to organise things, to form little committees in the house and to chair them. ‘He likes to talk, always’ she said.

Johanna: Any memories of your early school days worth sharing?

Paul: I went to local schools and then, from the age of 12 to 18, attended the Scientific A Section at Sint-Michielscollege in Schoten, where I completed my *maturiteit* (high school). Beyond my studies, I was good at sports, mainly running and volleyball, and I also did quite a lot of sailing, competing in real regatta with a friend of mine. I used to play an old one-string instrument called the *blazeveer* in a small music group that performed renaissance music on the streets and which became professional as soon as I left. Thinking back, I had an overly happy youth.

Christian: Which academic subjects were you particularly interested in?

Paul: From early on, I was very interested in history; I soaked up many books from the library. I still fondly remember one on the discovery of Tutankhamun's tomb. Travel inspired me and I very much liked writing poetry. I dreamt of becoming a writer or a historian. I enjoyed writing essays and was good at it; I vividly remember closing one of them with the sentence ‘Man created the tools to help him and now he is there to help the tools’. Whenever something happens in my life, I still like to express my experiences and feelings in writing, often in poems.

Johanna: How did you develop your interest in mathematics?

Paul: Mathematics came in later. I remember trying to come up with a formula for prime numbers while attending mass in Latin! However, an earnest training only came in the last 3 years of high school. It was good classical mathematics. It was only after I finished high school that the Bourbaki revolution took Flanders by storm. Dutch is one of the few languages in which the word for mathematics does not have a Greek root; it is *wiskunde*, literally ‘the knowledge of what is certain’. This term goes back to the Flemish mathematician, physicist and military engineer Simon Stevin (1548–1620). We studied analytic geometry, including conics in particular, and we meticulously drew Monge projections with Chinese ink on beautiful drawing paper, correcting every mistake with a razor blade.

Christian: Did you have any notable mentors?

Paul: Someone I looked up to was Omer Weyenberg at Sint-Michielscollege.¹ I asked him to feed me more mathematics, and he gave me a book on linear algebra. Although I no longer have the book, I still remember its smell. Through it, I discovered that there was so much more to mathematics than we were taught, and it became clear to me that this is my world. So I decided to study mathematics at university, and this I chose over civil engineering, where so many Belgians with talent in mathematics went because the title ‘Burgerlijk Ingenieur’ was particularly well regarded in society.

2 University Education

Johanna: You entered RUCA (Rijksuniversitair Centrum Antwerpen) in 1971, right?

Paul: Yes, and I must say that I found it extremely difficult for various reasons. We had set theory and ϵ - δ analysis from Day 1, and I was completely unprepared for this giant leap into abstraction, contrary to some other students. At the time, a major reform of Belgian mathematical education was being spearheaded by Georges Papy (1920–2011), an algebraist and educator, but my high school promotion was one of the last – if not the last – not to be exposed to it.

Christian: What was the curriculum like at RUCA?

Paul: It was heavily focused on the Bourbaki school of thought and extremely axiomatic. We studied Dieudonné's books, for instance. The failure rate was very high; only something like 20% of us survived the first year. I was very happy to have made it, despite serious problems

with my eyesight that developed at the time and continue to this day. For that reason, I always sat in the first row. But I got an extremely good education. The careful mathematical thinking that we were taught was remarkable. It showed me the beauty and importance of pure mathematics. To this day, I still put all the quantifiers in front of mathematical expressions [laughs], and I always insist on precise definitions, especially when discussing with practitioners.

Johanna: Is it during your studies in Antwerpen that you met your wife, Gerda?

Paul: Yes, we were in the same class, and she was excellent. We became acquainted through the *studenten parochie*, a room where many of us sat and studied course material together, mainly analysis, trying to move from a local to a global understanding. The camaraderie helped us to survive these straining times, and I developed a more intimate relationship with Gerda. Ultimately, she chose to go into mathematical education. We were married in 1975.

Christian: Did you study any probability or statistics?

Paul: I have a funny story to share about this, which shows the lack of consideration for probability and statistics in Belgium back then. At RUCA, our first probability course was devolved to Professor Paul de Witte, based at the University of Waterloo (in Canada, not in Walloon Brabant). He simply advised us to read Volume 1 of Feller's 'Introduction to Probability Theory and its Applications' and do all the exercises by ourselves, with no help from anyone whatsoever! He only intended to come over to answer questions in June, but because this was during preparation time for our exam period, we never actually met him. But I did fall in love with Feller.

Johanna: You then started your Licentiaat in 1973 at UIA (Universitaire Instelling Antwerpen). How was your experience there?

Paul: Very different! The UIA had just been established 2 years earlier, and we were very few students. Many of our professors were from the Netherlands, and they basically threw us into research from Day 1. We had to follow all the research talks, two to three per week, in various areas. For me the world of mathematics just exploded. I still remember a talk by Freddy Delbaen on game theory where he was using the Löwenheim–Skolem Theorem which says that if a first-order theory has infinite models, then it has models whose domains are only countable. It blew my mind.



Paul Embrechts in 1972 (age 19) with his future wife, Gerda Janssens.

Christian: Who were your mentors at UIA?

Paul: Jean Haezendonck (1940–1989) had a major influence on me. It is with him that I took my first steps in serious probability theory and developed my interest in it. He started his first lecture with Bertrand's paradox, and by the end of the term, he had covered all of Bauer's book on measure-theoretic probability. Can you imagine that by then, I could reproduce the proof of Choquet's capacity theorem, and yet I could not recognise a probability density if it hit me in the face? I received a very rich education there, but somewhat aloft of what mathematics is used for. In those days, there was a hype on analytic sets, which in two dimensions can be viewed as projections of Borel sets. Contrary to Lebesgue's claim, these sets are in fact not necessarily Borel. This topic, which is at the root of stochastic calculus, was the subject of my Master's thesis, hand-written in Dutch under Haezendonck's guidance.

Johanna: How did you end up going to Leuven for the PhD?

Paul: At UIA, we had one external elective. With my friend Paul Torfs, who was also interested in probability, I chose to take an applied stochastic process course from Jef (Jozef) Teugels in Leuven. We went there once a week. This course was a real eye opener and a very nice complement to the solid formal training I received from Haezendonck. Jef taught out of an early edition of a book by Sheldon Ross, and for the first time, I could measure the practical usefulness of stochastic processes. Soon after I graduated from UIA with highest distinction, a position opened at Katholieke Universiteit Leuven (KUL). I applied and became an assistant of Jef's in Fall 1975.

Christian: Tell us a bit about your time there.

Paul: Leuven was very different from the extreme axiomatic straitjacket of formalism that prevailed in Antwerpen. Jef was the first professor in probability and statistics at KUL and from a generation of young Flemish mathematicians who did their PhD abroad. He completed his degree at Purdue with Marcel Neuts (1935–2014). Jef brought internationalism to Leuven; he had many visitors. This was quite new and attractive to me. He made use of 'Capita Selecta' (Selected Topics) as a way to compensate for the lack of PhD courses. In those days, the Dutch were so far ahead of us in stochastics, and I took three courses from brilliant young Dutch probabilists: Laurens de Haan, Guus Balkema and Wim Vervaat (1942–1994), whom I sometimes call my triumvirate. Laurens taught out of his famous dissertation on extreme-value theory and regular variation, Guus' course on Brownian motion was based on a book project with Kai-lai Chung (1917–2009), and Wim² gave wonderful lectures on self-similar processes and sample-path properties inspired by his work with George O'Brien (1944–2018). I also recall taking a course on infinite divisibility from Fred Steutel (1931–2017). Through Jef and these courses, I entered the field of extreme-value theory and became more and more aware of applications. Leuven had a strong school in actuarial science, so my academic soup started to crystallise around extreme-value theory, regular variation and actuarial applications.

Johanna: Your first papers appeared in 1978. How did they develop?

Paul: This must have been sometime in the second year of my PhD studies. My first paper is a short note, a testimony to my transition from RUCA/UIA to Leuven. When I saw a theorem of Lukacs about integral transforms of probability measures on the real line, my Antwerpen training in pure mathematics prompted me to think that I can do this in a locally compact Abelian group. When the paper was accepted in 2 weeks (Embrechts, 1978a), I was ecstatic. I rushed home on my bicycle to share the news with Gerda, thinking that I had made it and that publishing papers would always be this easy [laughter]. All the more since my second paper was also accepted quickly (Embrechts, 1978b). Inspired by the course I took from de Haan, I proved a converse to one of his results having to do with second-order slow variation.

Christian: You started collaborating with Noël Veraverbeke and Charles Goldie soon thereafter, even before you completed your degree. How did this come about?

Paul: Noël had completed his thesis with Jef in 1974, and he was a natural person with whom to discuss actuarial applications. As for Charles, he was a student of Nick Bingham, who was a visiting professor in Leuven at some point. Charles was captivated by the notion of regular variation. He and I got along very well and later became very good friends. We started discussing subexponentiality, which was my thesis topic. We saw that several results that had been proved in ruin theory using regular variation could be generalised using subexponentiality.

Johanna: What was it like to collaborate at a distance in those days?

Paul: It was very different from today, but it was great fun! We sent hand-written letters back and forth. Let me give you a beautiful example: the story behind my 1979 paper with Charles Goldie and Noël Veraverbeke (Embrechts *et al.*, 1979). It grew out of an amazing coincidence. Noël and I had a draft of a paper in which we were comparing the tail of an infinitely divisible probability distribution with the tail of the underlying Lévy measure. We could first prove a result in the case of regular variation for compound Poisson distributions, then obtained a partial generalisation to the entire class of infinitely divisible distributions under the broader condition of subexponentiality. The full if-and-only-if version, which we expected to hold in the latter case, eluded us. Then one day, I received a letter from Charles in which he said that he had recently proved the convolution root closure of the subexponential class but that he had no idea what to do with it. Amazingly, this was exactly the result Noël and I needed! It led to this nice paper which we coauthored in *Zeitschrift für Wahrscheinlichkeitstheorie und verwandte Gebiete* and which I presented in 1978 at my first international meeting, the 8th Conference on Stochastic Processes and their Applications organised by the Bernoulli Society in Canberra, Australia. It is there that I first met Makoto Maejima, my future collaborator and friend to this day.

Christian: You really matured fast into an independent researcher!

Paul: Jef was excellent at creating an active research environment that was enriching from a mathematical, educational and human point of view. I was very lucky that he introduced me to an interesting area and that beyond that, he let me develop independently. Although we discussed mathematics together, I always strove to find my own way. The fact that we could often publish short papers back then gave us freedom to express ideas. We did not benefit from all that much guidance on how to write, but we learned on our own in the process. I was also lucky to get a lot of valuable editorial support, as papers were still carefully copy-edited in those days.

Johanna: You completed your DSc in 1979. What form did your thesis take?

Paul: In those days, you had to write two theses in Belgium. My main thesis was on subexponential distributions. It was written in Flemish in the classical mode. My second thesis needed to present a mathematical result outside of my field of research to demonstrate breadth. I used my extension of the theorem of Lukacs to that end. The thesis defense was not very formal, and anyone interested could come, including family and friends. The thesis committee consisted of Jef Teugels, Guus Balkema, Nick Bingham, Noël Veraverbeke and a Chair. After my talk, there were questions from the audience and then came some serious grilling from the committee [laughs].

3 Early Academic Career

Christian: What happened after your degree was completed?

Paul: My defense was on a Friday, and the following Monday, we were headed for a 1-year postdoc with Nick Bingham at Westfield College, University of London. Gerda and I then had two children: Krispijn, born in 1976, and Eline, who arrived in 1978. We packed everything into our little Renault 5 and off we went. That year, I continued to interact with

Charles Goldie, who was in Sussex (Embrechts & Goldie, 1980; 1981). It was especially nice that Nick organised for me to lecture at most major universities in England. This way, I met an entire generation of young probabilists such as Adrian Baddeley, Tim Brown, Chris Rogers and many others.

Johanna: In 1980, you then returned to Leuven.

Paul: Formally, I was a Research Assistant there until 1983, but you have to think of it as a postdoc position. If you wanted a faculty position in Belgium back then, you had to apply for new courses as they became available, and once you clinched one, it basically remained yours for life. With enough courses under your belt, you could eventually become a professor; this is of course a somewhat simplified version of the academic ladder that prevailed at the time. As statistics was underdeveloped in Belgium, Jef and I saw an opportunity there, and he advised me to go back to England and hone my skills in that field at Imperial College, London.

Christian: That department was the center of the statistics world in those days!

Paul: Absolutely, it was an amazing place! I met so many influential people there, beginning of course with David Cox with whom I had the chance to discuss on many occasions. I truly immersed myself in the good old English statistical school, followed courses, went to seminars, read books on survival analysis and attended my first Royal Statistical Society meetings. Incidentally, this is where my ties to Canada started to develop. For one, Agnes Herzberg became a very close personal friend.

Johanna: And what happened when you returned to Leuven?

Paul: I came back from London full of enthusiasm, my mind set on building statistics in Leuven. The expectation was that I would be a permanent member of staff after I came back. So much so that I had already arranged for a 1-year visit of Makoto Maejima and his family, and I committed to organise the third European Young Statisticians Meeting in Leuven in 1983. But then disaster struck and really struck. Instead of having a permanent position, I had none at all. All that could be arranged for me was a short-term interim in replacement of Jan Beirlant while he was doing his military service. What do you do then with a family with two children? In the absence of any better prospect, I decided after a few months to apply for a position at the Generale Bankmaatschappij in Brussels. They were hiring in the field of informatics, and although I had no specific computer skills, I must have advocated well for the advent of mathematics in banking and was hired. I learned APL; my task had to do with the automation of portfolio management. It could have been an interesting career. Above all, it allowed us to continue to live in Leuven, where we were very happy as a family. At that point, I closed the door to science.

Johanna: How did you open it again?

Paul: In late spring or early summer, 1983, Ole Barndorff-Nielsen and David Cox were in Belgium for a PhD defense in Namur. They found it a pity that I had left academia and came to visit me at home. I was extremely flattered that they offered their support. David then encouraged me to apply for a Statistics Lectureship position at Imperial, so I did although I thought the chances were slim. Then one evening, I got a phone call from Harry Reuter (1921–1992), who was then Chair of Mathematics at Imperial College, London. He offered me the position. I was dumb-founded. The decision to go would have many implications for the family. So that night, Gerda and I opened a bottle of wine and talked about it for a long time. And then at one point she said 'We must go because I know academia is the only place where you'll be happy professionally'. So I accepted the position.

4 London and Limburg

Christian: Did going to England for the third time make the relocation easier?

Paul: It was actually very difficult at the start and financially challenging throughout our stay there. I went alone at first and lived for 6 months in a bedsit in Hounslow East, near Heathrow.

Every weekend, I looked for places to live and schools for the children, but it was plain impossible to afford anything; there was simply no arbitrage in that market. Then Charles Goldie went on sabbatical to Stanford, and he let us his house in Brighton. At last, the family could come, and we had perhaps the greatest time of our lives, with few responsibilities and things to worry about. Our children went to a local catholic school which they enjoyed; I remember playing Julius Caesar in one of the school plays. We made many trips all over England and during weekends often visited National Trust gardens. We later rented another house in Brighton, where we were set to stay for good, even though it took me nearly 2 hours each way to commute by train to and from Imperial.

Johanna: What was it like to be back at Imperial as a Lecturer?

Paul: Scientifically, it was great. It was such a powerhouse! I met dozens of people and made many friends in the statistical community. David Cox's bright and humane view of statistics and its role in society was so inspiring. Suddenly, amazing people like John Nelder (1924–2010), Henry Wynn and so many more were my colleagues. I felt close to Richard Smith and the other two junior lecturers, Terry Lyons and Peter McCullagh, and I became acquainted with Anthony Davison, who was a PhD student of Cox's. With her great loyalty to the British statistical heritage and her warm hospitality, Agnes Herzberg introduced me to Frank Yates (1902–1994), brought me to Rothamsted to see Fisher's original split-plot design and so on. And then there were all the visitors; it felt like the whole statistical world was coming by. Alan Agresti and Nancy Reid became good friends, I met all the Danish group, and I even had lunch with John Tukey (1915–2000). There was a lot of excitement and discussion within the group.

Christian: What were your duties?

Paul: I was Brian Ripley's successor in a sense. I took over his time series course for which he developed computer programs. This was quite new to me! I also taught multivariate analysis and applied stochastic processes, and I even got involved in starting an actuarial program. There were many amazing students, too, such as Jonathan Tawn whom I taught as an undergraduate!

Johanna: What about research-wise?



Brian Ripley (left), Paul Embrechts (center) and Richard Smith (right) in 1984.

Paul: In Leuven, I had developed a research program with Makoto Maejima, and I had linked up with Edward Omev, a clever PhD student of Jef Teugels' working on analytical aspects of regular variation. This kept me busy for a while and led to nice papers (Embrechts & Maejima, 1984; Embrechts *et al.*, 1984; Embrechts & Omev, 1984). Then with Agnes Herzberg I explored the properties of Andrews plots (Embrechts *et al.*, 1986; Embrechts & Herzberg, 1991; Embrechts *et al.*, 1995). At Imperial, there was a buzz around higher-order asymptotics and differential geometry shedding light on the interpretation of the coefficients in the expansion of the log-likelihood function. This inspired my papers on saddlepoint approximations for compound Poisson and Pólya processes with Jens Jensen, Makoto Maejima and Jef Teugels (Embrechts *et al.*, 1985a; Embrechts *et al.*, 1985b). Had I stayed there, I feel I could have provided a good link between statistics and actuarial science.

Christian: What prompted you to leave Imperial after only 2 years?

Paul: Eventually, it became clear that there were only limited prospects for promotion at Imperial for all four of us lecturers, Richard, Peter, Terry and me. So we started to seek opportunities elsewhere, and all left at about the same time. Richard Smith went to Guilford, Peter McCullagh to Chicago and Terry Lyons to Edinburgh. David Cox himself left not much later for Oxford. I received offers from two universities in Belgium, Leuven and Hasselt, and I ended up choosing the latter.

Johanna: You were a Docent at Limburgs Universitair Centrum (LUC) in Diepenbeek from 1985 to 1989. What do you recall from that period?

Paul: LUC, now called Universiteit Hasselt, was founded in 1971, and when I joined, it had only undergraduate programs. But we were four young colleagues there in statistics, Herman Callaert, Paul Janssen, Noël Veraverbeke and me; all good friends and 100% committed. It was one of those cases when $1 + 1 > 2$. Our goal was to build up a Master's program in biostatistics. We reached out to David Cox and Steve Lagakos (1946–2009) at Harvard who lent us their support; with their encouragement, people like Louise Ryan, Nick Lange, Adelchi Azzalini, James Lindsey and Agnes Herzberg came for a few months and taught courses. We started to introduce computing into the curriculum. The program became very successful and one of the best in Europe; many top Belgian statisticians were trained there, including Irène Gijbels and Ingrid Van Keilegom.

Christian: How did this influence your research activities?

Paul: That time was not my most active research-wise. I didn't write any big papers, but I was very much involved in societal work. Apart from building up the program, I helped set up a statistical consulting service and worked on a cancer registry with Eugène Schifflers. Back then, there was none in Flanders. Eugène and I also wanted to write a book on occupational cancers; we already had many of the world's top experts in cancer epidemiology lined up to contribute, but the project fell through because we couldn't get funding. This is my best book never written. Between moving to Hasselt, welcoming Frederik as our third child in 1986, various professional involvements, and writing a couple of papers on chest pain using classification and regression trees (Buntinx *et al.*, 1991; 1992), I had a pretty full life.

Johanna: Not to mention that you were Scientific Secretary of the Bernoulli Society!

Paul: Jef Teugels was among the founders of this society, created in 1975, and got me involved early on. I valued the Society's efforts to reach out to researchers beyond the Iron Curtain and help them travel to the West and network through meetings. A case at hand are the European Young Statisticians Meetings, a continuing tradition which I helped to establish. It required a lot of effort, and funding was critical, but the meetings were very educational, with about 50 people from the whole array of probability and statistics, and no parallel sessions. It was a worthy cause, and I ended up serving as Scientific Secretary from 1987 to 1992.

5 Move to ETH Zürich

Christian: You finally moved to ETH in 1989. Why and how?

Paul: Although I enjoyed the environment in Hasselt, deep down, I am not a biostatistician. I felt that this is not really what I can give to the broader world. So I had always been clear with my colleagues that if the right offer came, I might go. I was approached regularly; Antwerpen, among others, sought me as a potential successor to Jean Haezendonck after his passing, but it wasn't clear when the position would open. In 1987, I met Hans Föllmer in Thessaloniki, where I was to give a talk on martingales and insurance risk based on joint work with my first PhD student, Angelos Dassios (Dassios & Embrechts, 1989). Hans told me that Hans Bühlmann was retiring from his professorship at ETH to become President of the institution and that they were seeking to fill his position. He said they wanted to hire someone recognised by the department's mathematicians as one of their own, but with interest in insurance and statistical applications and capable of bridging the gap between ETH and industry. This was my dream combination!

Johanna: What was the application process like?

Paul: At first I thought this was too long a shot, but Hans Föllmer encouraged me to apply, and so did I in late 1987. After a long selection process, I learned in early 1989 that the position would be offered to me and that we could start discussing the conditions. Gerda and I were flown in for 2 days and were impressed how well we were treated and how serious and thorough the negotiations were; the possibilities were just incredible. I left with a skeleton of a contract, and on 1 November 1989, I became at 36 ETH's youngest Full Professor.

Christian: Presumably it was easier to settle in Switzerland than in England!

Paul: Of course it's always a struggle when you move abroad, but we settled in very well. We chose to live in the canton of Aargau, which involved a bit of commuting for me, but we were quickly integrated into the village community. Gerda soon joined the church choir, our children were well received in school, and we have lived there ever since. We even recently became Swiss citizens.

Christian: Was the professional transition equally smooth?

Paul: As a successor to Hans Bühlmann, I had some very big shoes to fill; he left such a legacy! I also had to be recognised as a mathematician within one of the top mathematics departments in the world. Moreover, when I started interacting with industry, I realised that I had become one of the faces of ETH mathematics to the outside world. So my position came with a lot of expectations. The obligations were serious, too. My mandate was to build up a program in insurance mathematics, and I was alone to do it. When I arrived, I was the only one in probability in the department. Hans Föllmer had gone to Bonn, Hans Bühlmann had become President of ETH, and there were only two statistics professors, Frank Hampel (1941–2018) and Hans-Rüdi Künsch.

Johanna: You must have felt quite isolated at the start. Is it then that you linked up with Hans-Jakob Lüthi?

Paul: Soon after my arrival, I was appointed interim Chair of ETH's Institute for Operations Research (IFOR) with a mandate to phase it out because operations research was deemed at a low point worldwide. This seems odd from today's perspective as it has become such a key discipline. So I spent part of each week at IFOR and could see the great work that was being done there. After a few months, I went back to the President arguing against the closure because (a) the research is important for Switzerland and (b) nobody else at ETH can do it. Instead, I proposed to reorganise it, which I did, and we did increasingly well. Then Hans-Jakob took up the position as a new professor of Operations Research in August 1993, and we interacted closely ever since. He replaced me as Chair of IFOR and the institute continued to flourish.

Christian: How did you go about building the actuarial program?

Paul: The insurance industry started having new needs and the *Schweizerische Aktuarvereinigung* (SAV), the Swiss Association of Actuaries, had approached ETH sometime before my arrival with a request to update actuarial education and make it more in tune with practice. I gradually developed my contacts in the world of insurance. Having Hans Bühlmann around opened many doors. Through interactions with the SAV, I set up a teaching program in insurance mathematics based on a strong mathematical footing. I brought a lot of probability and statistics into it, while keeping an eye on the developments in the European Union to ensure that we had a EU-recognised diploma. I later joined SAV's Board in 1995 and became the Editor of *ASTIN Bulletin* the same year, a position that I held for 10 years (Embrechts, 1995). I also became an officially SAV-accredited actuary in 1998. Starting with Hanspeter Schmidli in 1992, I had more and more students working on relevant issues in finance or insurance, and many of them had careers in industry.

Christian: When you speak of the insurance industry's new demands, I am reminded of Hans Bühlmann's vision of 'Actuaries of the Third Kind' (Bühlmann, 1989).

Paul: The world of finance and insurance was in a state of flux, and the interplay between finance and insurance was forming, which Hans Bühlmann anticipated and promoted very strongly early on. Actuaries started to realise that there needs to be a transfer from a pure liability side to a combined asset-liability approach. And at the time, there was the explosion of mathematical finance all over the world. With Hans Föllmer gone, I could clearly see the need to rebuild mathematical finance at ETH and to hire a new professor in that field.

Johanna: Is this how Freddy Delbaen came to ETH?

Paul: Eventually, yes, but I first had to work hard to secure the position. I started by offering a course in mathematical finance from the book of Lamberton & Lapeyre (1992) to about 50 students. I was pleasantly surprised that several of my colleagues decided to attend, including Michael Struwe, Hans-Jakob Lüthi, Urs Kirchgraber and Helmut Hofer. They found the mathematics interesting and agreed to support my initiative to create a position in that field. Then negotiations with industry started. In those days, if industry had an honest request for a new field of research, ETH was very supportive in discussing the possibility of a new professorship. As it turned out, I was Department Chair in 1994–1995 when we started screening the candidates. We ended up hiring Freddy in 1995.

Christian: How did the move to ETH impact your own research?

Paul: My work gradually turned away from the road I had embarked on in Limburg and was now entirely in the direction of insurance mathematics and finance. My interest in this field was there before, but now, it fully resurfaced. Besides, I have always been attracted to statistical and numerical work and saw the importance of relevant examples. Through the external contacts that I began to develop, I could start to build up a fundamental research program around concrete problems from industry. Actuaries of the third kind were concerned with matching long-term liabilities with short-term investment. However, introducing financial products to the insurance market is far from straightforward. Adding actuarial constraints to familiar investment portfolio problems immediately gives rise to interesting and often very difficult mathematical questions. I initially got involved in alternative risk transfer.

Johanna: How did you foster fruitful research collaboration with industry?

Paul: I was always attracted by making mathematical results accessible to people and by explaining why they are relevant for them. I am open minded and curious about questions from industry. People know that they can always approach me and I'll listen. For example, I once got a phone call from someone from industry about a preprint of the now famous paper by Heath *et al.* (1992). 'We saw this very mathematical paper,' they said; 'would it be possible to discuss it with you?' So I went there, and we worked through the paper together in detail. Such was the atmosphere in Zürich and the nature of industrial collaborations in those days! On another

occasion, Hans-Jakob Lüthi and I were invited by, I believe, the Swiss Bank Corporation (SBC) to discuss ‘Value-at-Risk’ – we said value-at-what? This was in 1994, and JP Morgan had just introduced VaR into its RiskMetrics variance model.

6 The Birth of Risklab

Johanna: RiskLab was founded in 1994. Tell us about that.

Paul: As I said, there were just so many interesting mathematical problems out there coming to us from industry. Hans-Jakob Lüthi and I could sense a serious interest in mathematical work being done at the intersection of finance and insurance. So, we thought, why not make mathematical support available to all as a way to interact with industry? Hans-Jakob and I then founded RiskLab on 7 October 1994, as a precompetitive research platform supported by industry. The precompetitive nature of RiskLab was crucial to us; we did not want to create a consulting unit.

Christian: Could you elaborate on the meaning of ‘precompetitive’?

Paul: We wanted to do joint research with industry, through Master's and PhD students, postdocs and our own work, on topics that we would find methodologically interesting and that would be relevant to them and that could be transmitted and discussed openly. For example, we would study problems around VaR or risk aggregation, rather than a specific model of one concrete bank. So in the end, three large Swiss banks joined forces and formed a *Forschungsinteressengemeinschaft*, a platform, backed up by legal documents, to support research at ETH. Through this initiative, we obtained about one million dollars per year to run RiskLab.

Johanna: How did you go about identifying RiskLab projects at first?

Paul: To launch RiskLab, we had a whole day organised. Hans-Jakob and I invited some of the top people from these three banks, chief risk officers and researchers, and the head of the Basel Committee. A psychology professor from Universität Zürich acted as a moderator. We asked the industry representatives to write down the main problems they were interested in collaborating with us. So they did, and we discussed these topics; the regulators were mere observers because of legal constraints. At the end of that day, we settled on five topics or so that were of interest to them and where we thought we could contribute. So we had a Master's or PhD student working on each one of these topics under joint supervision from the academic and industry side. The precompetitive nature of the projects ensured that the research coming out of this could be published. This worked wonders until the early 2000s.

Johanna: How did you share your results with industry?

Paul: The main outcomes of our initial efforts were presented at the first Risk Day in 1998, a day-long conference for researchers from academia and industry. If you look at the program, it's all there: talks on extremes, coherent risk measures, pitfalls of correlation, portfolio analysis under nonstandard constraints – it was just incredible. Without RiskLab, all this work and its relevance for practice would hardly have been possible. Ever since, Risk Day has been a fixed point in the Zürich insurance and finance calendar.

Christian: Your first book with Claudia Klüppelberg and Thomas Mikosch is also from that period. What brought you to write it?

Paul: Claudia and Thomas were my first postdocs. Claudia visited me at Imperial, and I supervised her PhD thesis on subexponential distributions. Thomas and I met in Dresden before the fall of the Berlin Wall. I invited him to visit me in Limburg, but by the time he was ready to come, I had moved to Zürich. When the three of us eventually converged at ETH, we had the idea that we should do something about extremes. In 1994, we taught a course on modelling extremal events in insurance at the 11th International Summer School of the Swiss Association

of Actuaries. Then one day, we sat here at ETH in the Dozentenfoyer and thought: ‘Why not turn our lecture notes from the summer school into a book?’ So we did. . .

Johanna: . . . and it turned out to be very readable!

Paul: From the start, we wanted the book to be accessible broadly, but it wasn't easy to write. Our views of the book didn't always agree. At the time, I was gradually moving away from a purely mathematical style and towards a more applied, pedagogical one while not compromising too much on exactness. Thomas, however, having been trained at the Department of the Steklov Institute in St. Petersburg, very much insisted on rigour. For example, we decided to leave out Leadbetter's theorem on the convergence of joint exceedances to a non-homogeneous Poisson point process in \mathbb{R}_+^2 because to do so rigorously was simply impossible without a much deeper probabilistic background. Compromises like this one took time. One morning, in Oberwolfach, Thomas came down and said he had dreamt of being in a boat with two other people and wanting to throw them overboard! We finished our EVT book while I was on my first sabbatical at Cornell in Fall 1996 (Embrechts *et al.*, 1997). The time difference made our collaboration rather efficient!

Johanna: Tell us more about your sabbatical; why Cornell?

Paul: Of course the whole environment there was very attractive, as was the prospect of visiting Sid Resnick and Gennady Samorodnitsky. My contact with Sid goes back to the Brighton period; we became instant friends. I had a great time in Ithaca, but short: I stayed less than 2 months in total. I did not want to impose another move on the family.

Johanna: Did you write any papers together?

Paul: Sid, Gena and I wrote the paper ‘Living on the edge’ for *Risk Magazine* (Embrechts *et al.*, 1998). The title of course is Sid's. The magazine was a platform for practitioners to learn about relevant mathematical discoveries, and we wanted to make extreme-value theory techniques known to a more general audience. We followed up with another paper in the *North American Actuarial Journal* (Embrechts *et al.*, 1999b). This was 10 years before the Black



Paul Embrechts (left), Thomas Mikosch (center) and Claudia Klüppelberg (right) working on their book at the Mathematisches Forschungsinstitut Oberwolfach, in Germany.

Swan!³ Over the years, I wrote several other papers with Gena, in particular when he visited me later on sabbatical (Embrechts & Samorodnitsky, 1995; Embrechts *et al.*, 1998; Embrechts & Samorodnitsky, 2003; Embrechts *et al.*, 2004).

Christian: In that period, you also collaborated with Chris Rogers and Marc Yor (1949–2014).

Paul: My first PhD student, Angelos Dassios, had proven an absolutely remarkable identity in law for the α -quantile of a Brownian motion with drift. Chris, who was a close friend since my time in London, Marc and I had a different Ansatz and gave two different proofs of this result (Embrechts *et al.*, 1995). It was beautiful mathematics.

Christian: Indeed.

Paul: But then I must tell you about the quantile story! I mentioned this work in the course on mathematical finance I was teaching at ETH in 1993–1994. People from the Swiss bank UBS participated and found the course interesting, so they invited me to come over and give a talk on my work. I was getting ready for this experience, which was then new to me, and as the date was getting closer, they said ‘great that you are coming; we’ll talk about quantos’. I replied that I was working on quantile options, not quantos, having no idea that the latter were options where at pay-off, you can change the currency! Anyhow, we had a nice afternoon; I talked about extreme-value theory and even mentioned the notion of what would later become known as the expected shortfall; it was very natural from the point of view of extreme-value theory. Then came payday. Much to my astonishment, I received a little wooden box, and when I opened it, there were three ounces of pure gold!

7 Quantitative Risk Management

Christian: Then you hit another gold mine with copulas in the late 1990s!

Paul: This started as a typical RiskLab story. One day, two actuaries came to my office with a problem of linking two log-normal variables, with parameters (0, 1) and (0, 16), say, with a joint model so that they have a given amount of correlation, say 20%. After some thought, I realised that there can be no such model. My colleague and friend Hans-Rüdi Künsch pointed out the idea of copula transform to me, and this was indeed a fruitful way to look at the problem. Industry obviously had an issue with understanding non-normal dependence, diversification and aggregation, among others. The concept of copula turned out to be extremely useful for this purpose, and I happened to have the right people around me to bring it to the fore.

Johanna: You are referring to Alex McNeil, right? How did the two of you meet?

Paul: Alex was key in bringing statistics into quantitative risk management (QRM). He came to Zürich in 1993 for a postdoc with Andrew Barbour after his PhD at Cambridge. Initially, he worked on medical statistics, but then he got interested in finance and insurance, and I could see that this is someone who could help me develop the statistical side of insurance mathematics. So I offered him a second postdoc in 1996. He later became an Assistant Professor in 1999 and ended up staying at ETH until 2006. He and I had this bright Master's student, Daniel Straumann. When I alerted Alex and Daniel to the issues around correlation and dependence, it truly fell on fruitful ground! We wrote a RiskLab report in 1998 on the pitfalls of correlation, which to this day I find very well written, and for the right audience. Daniel presented it at the first Risk Day in 1998, and I gave my first talk on this topic at Columbia University in early 1999. In the audience was David Li, who was later unfairly blamed for ‘the formula that killed Wall Street’ (Salmon, 2012; Puccetti & Scherer, 2018). All the examples that later served to illustrate the misuse of Gaussian copulas were in my talk! But then I took a decision which I still regret.

Christian: What was that?

Paul: We should have published our report right away, but we didn't. Instead, we wrote a short piece for *Risk Magazine* (Embrechts *et al.*, 1999a), and the full paper only appeared in 2002 as a contribution to a Cambridge meeting (Embrechts *et al.*, 2002). Now I think we should have submitted it to a top finance journal. I would be curious to know how it would have been received! But we didn't do it because we didn't want the referees to change one word of it.

Johanna: It gave a lot of visibility to copula modelling in risk management circles.⁴ This article, in its various declinations, is among your most-cited papers.

Paul: Absolutely, and it reached a wide audience. It became one of my most important papers, along with the 'Academic Response to Basel II' to which I contributed (Daniélsson *et al.*, 2001). That document was posted on the website of the Basel Committee for Banking Supervision (BCBS) as an official response to the new regulatory guidelines. It really had a major, lasting impact.

Christian: Basel II is the second set of international banking regulations defined by the BCBS. What were the main messages of your response?

Paul: The report grew out of a conference organised by the Financial Markets Group and the Centre for Economic Performance of the London School of Economics (LSE) in May 2001. Here, I got to interact with some of the very top people in finance, such as Jón Daniélsson,



Paul Embrechts (left), Alexander McNeil (center) and Rüdiger Frey (right), coauthors of the bestselling QRM book by McNeil, Frey & Embrechts (2005), at ETH on 8 April 2008. Photo credit: Giovanni Puccetti.

Charles Goodhart and Hyun Song Shin. This was a very interesting experience. In this document, we pointed out what went wrong with financial regulation. We put our fingers exactly on the weak spots, and this in 2001! We were not after predicting when a crisis would come, but rather what could go wrong if the financial markets turned. And we were 100% right. We pointed out several important issues: the lack of systemic component in banking regulation, too much reliance on the rating agencies – who rates rating agencies? – not to mention the serious issues with VaR as a measure of risk. There is no way VaR can be estimated reliably at the very high level of 99.9% prescribed by the BCBS, especially not in the presence of complex interdependencies as in the case of operational risk. Our main message was ‘Rethink before it is too late’.

Johanna: Is there a connection here with your presence on the Board of Directors of Julius Baer, which is one of the largest private Swiss banks?

Paul: Around 1997, Julius Baer was in the transition from Basel I to Basel II, and they needed somebody at the board level to help with this. Richard Olsen, who was a member of the larger Baer family, recommended me to them. I was then approached and eventually became a member of the Board after being elected at a meeting of the bank's equity holders. In the end, I stayed on for 11 years. Being on the Board meant that I shared a legal responsibility for the success of this transition. I studied all the Basel documents on banking regulation very carefully, and more importantly, I got to know issues of financial regulation really from within. Being a mathematician with this internal insight also made me more visible to the regulators.

Christian: You mentioned Richard Olsen; who is he?

Paul: A very interesting person! He started a company in Zürich, called Olsen Associates, with the aim of building a real-time information system for the financial industry. These were pioneering days of high-frequency data, which were then hard to collect. In 1995, I was involved in a conference he organised on high-frequency finance. Many of the top economists came, including Robert Engle and Benoît Mandelbrot (1924–2010). Participants were given high-frequency data and discussed them openly. This inspired my work on heterogeneous autoregressive conditional heteroscedastic processes with Gena, Michel Dacorogna and Ulrich Müller (Embrechts *et al.*, 1998); Rudolf Grübel and I later proved that these processes are heavy-tailed (Embrechts & Grübel, 1999).

Christian: In the same period, you were also involved with Swiss Re and Swiss Life. What was your experience there?

Paul: At Swiss Re, I was an independent *mathematischer Revisor* from 1997 to 2003. In this capacity, I reported to the Board of Directors about reserve calculations and assessed whether they are in line with the regulatory requirements. I could do that only on a sampling basis, of course, but I got to discuss with their internal actuaries and looked at special cases. At Swiss Life, which is the second largest Swiss life insurance company, I joined the Board in 2003 and remained until 2011. As a board member, I was co-responsible for setting the strategic guidelines for the company and for senior appointments; I also sat on several committees. Being involved with these three companies gave me a unique perspective on practice and a vast body of experience. While this may be relatively common for economics or finance professors, it is rather rare for mathematicians! I must say that I owe this very much also to the whole set up we have here in Switzerland, which favours close collaboration and contacts between industry and academia. To some extent, this experience was translated into research. More importantly, it contributed to my global view of where insurance and finance fit in the world of risk management.

Christian: Your familiarity with industry concerns also shows in your research papers, notably through the use of copulas to explore the impact of dependence on portfolios.



From left to right: Louis and Annabelle Chen, Gerda Janssens, Makoto Maejima and Paul Embrechts at the 7th World Congress in Probability and Statistics in Singapore, 17 July 2008.

Paul: Yes, in 2003, I had this paper with two of my PhD students, Andrea Höing and Alessandro Juri, on extending some of your own results on distributional bounds for functions of dependent risks (Denuit *et al.*, 1999; Embrechts *et al.*, 2003). With another doctoral student, Alexandra Dias, I also looked into change-point analysis for dependence structures in finance and insurance (Dias & Embrechts, 2002), and dependence structures for multivariate high-frequency data in another paper with a former postdoc of mine, Wolfgang Breymann (Breymann *et al.*, 2003).

Johanna: Then all this came together into your QRM book with Alex McNeil and Rüdiger Frey (McNeil *et al.*, 2005). Tell us more about that.

Paul: By the mid-1990s, I had a good overview of the relevant questions in risk management in finance and insurance, so I started thinking of the next book. Then Rüdiger joined RiskLab as a UBS postdoctoral fellow in 1996. I have to say that I was always rather personal in choosing postdocs, bright people with interesting skills and the right personality to fit in. He linked up very fast and very closely with Alex. The three of us were very complementary: me, the mathematician, Alex, the statistician, and Rüdiger who brought in economics and in-depth knowledge of credit risk. QRM is an exciting, interdisciplinary area, but also dangerous since you keep sitting between various stools. It is not about a single technique but about a combination of various tools, such as extremes, copula modelling, time series techniques and of course concepts from finance and economics. So we complemented one another very well. Alex and Rüdiger were also very industrious; we started teaching summer courses, and at one point, the

two of them even thought of founding a consulting company. We finished the book during my second sabbatical at LSE.

Christian: That was from 2003 to 2005. What was it like to be at LSE?

Paul: These were exciting times! I became Centennial Professor of Finance and kept this appointment for 2 years. I spent time there and taught courses. It was a very interesting appointment, in that I was located in a department of accounting and finance. I got in contact with real finance people like Jean-Pierre Zigrand, and of course Jón Danielsson, Charles Goodhart and Hyun Song Shin. I even taught a course on risk management jointly with Hyun Song Shin. I really had to stand on top of my economic and financial toes to play along with these people!

Christian: Meanwhile, you wrote a third book, this time on self-similar processes. . .

Paul: It actually preceded the QRM book and was the result of joint efforts with my friend Makoto Maejima. It stemmed from an introductory paper we published in a special issue of a physics journal dedicated to Hans Bühlmann on his 70th birthday (Embrechts & Maejima, 2000; 2002).

8 Exploring New Research Horizons

Johanna: How did the environment at ETH evolve in your field after 2000?

Paul: For Risklab, the early 2000s were a critical period. In a sense, it started outgrowing its success. Swiss Re, a major player in insurance, became part of the *Forschungsinteressengemeinschaft* (FIG) along with the banks, and we needed a research director. Uwe Schmock held the position for a couple of years. Then we tried to get an extra professorship for RiskLab, and although the banks would have been potentially ready to support it, it did not materialise. After that, the FIG eventually dissolved, and there were no longer specific projects supported directly through RiskLab with industry, although we still had many contacts. There were doctoral and postdoctoral positions supported by industry, for example, by SCOR, where I had a very successful contact with Michel Dacorogna. At ETH more broadly, the finance group was growing, Delbaen was there and later Martin Schweizer. I also connected with the economists at Universität Zürich. Together, we set up a joint Master's program in quantitative finance, which offers a very nice combination of the quantitative, mathematical side and the qualitative, economics and finance side.

Christian: Is it not also about then that Mario Wüthrich joined the group?

Paul: Mario's hiring in 2005 was a turning point in my personal career at ETH. In the late 1990s, there were increasing demands from both SAV and the European Union for specific professional components beyond mathematics in actuarial education. I had people from industry with PhDs in math teaching, revamping the courses and consulting on MSc theses. It then became clear to me that running the actuarial program was just too much for me. After intense discussions, the department agreed to vacate a position of senior scientist with tenure, in RiskLab, to support me in this task. I needed a real mathematician with practical experience, who would be interested in taking over the organisation of actuarial education. Mario, who had done his PhD at ETH with Alain-Sol Sznitman on percolation and random media and had worked at Winterthur Insurance, was God-given. He eventually became *Titularprofessor*, the Editor of *ASTIN Bulletin*, and a star in actuarial science worldwide. Paraphrasing my old school essay, I might say 'I appointed Mario to help me; now I am there to help Mario'. We also have *Titularprofessors* like Alois Gisler and Michael Koller teaching at ETH who both have considerable practical experience. As I retire, we have an absolutely wonderful actuarial program.

Johanna: What about your own research?

Paul: I started consolidating major projects into a serious mathematical research program in QRM. What interested me particularly, and still does, are problems around model uncertainty, risk measure assessment, risk aggregation and allocation. There are many mathematical issues there which I extracted from questions that came to me from industry. Starting with Alessandro Juri and Andrea Höing, I had a whole suite of students working on problems around VaR of portfolios under restrictive dependence assumptions. Then the main contribution came from Giovanni Puccetti. He and I published a paper in 2006 where we derived a lower bound on the distribution function of a combination of dependent risks with fixed marginals (Embrechts & Puccetti, 2006a; 2006b).

Christian: Your collaboration with him went well beyond his PhD, though.

Paul: Indeed, he has become a very important collaborator of mine. For example, we derived bounds on the sum of dependent risks having overlapping marginals (Embrechts & Puccetti, 2009). With Philipp Arbenz, we also developed algorithms for the fast computation of the distribution of a function of dependent random variables (Arbenz *et al.*, 2011; 2012). Later with Ludger Rüschendorf, Giovanni and I exploited the rearrangement algorithm to compute bounds on the best and worst VaR (Embrechts *et al.*, 2013). Then as of 2013, Ruodu Wang, who is based in Waterloo, started visiting RiskLab regularly. He and Giovanni closed the gap on the sharpness of the lower bound from our 2006 paper. There is a lot of interesting work building up a real edifice, I think.

Christian: When I came to ETH on sabbatical, in Fall 2006, you were also working on a book with Guus Balkema on high-risk scenarios.

Paul: Guus and I wanted to determine the conditional distribution of a random vector given that it lies in a half-space, which could mean a portfolio value representing a high loss, a high-risk scenario. It led to a long preprint, which is very much Guus'; we discussed this extensively, but of course his mathematics was at a more abstract level. We started to develop a whole theory that became too big, so we published it as a book (Balkema & Embrechts, 2007). Then I had Natalia Nolde as a PhD student; she had actuarial and statistical training from Simon Fraser University and came to me to learn more mathematics. We ended up working with Guus on this very difficult subject at the intersection of geometry and extreme-value theory. She worked very hard and managed to use the theory Guus and I developed to solve very concrete problems. Imagine you have a multivariate distribution, say skew elliptical, and you want to prove asymptotic tail dependence. You have some analytical conditions there, but can you find geometric ways of proving it by looking at the shape of level sets? She did, and in a brilliant way (Balkema *et al.*, 2010; 2012).

Johanna: What about your work on operational risk?

Paul: I am glad you asked that question! Of course, as you know, the whole story started with the conference and the course you, Valérie Chavez and I taught at the Boston Fed. Then the three of us wrote this paper on infinite mean models (Nešlehová *et al.*, 2006), and more followed, with Dominik Lambrigger, Matthias Degen, Marius Hofert, Valérie and others; my work on risk aggregation is also very much related. It became a rich, wonderful topic. I got very much involved, until today, in the whole discussion around very heavy-tailed models, which you now also find in climate and cyber risk. The reason why I started this early was because of Julius Baer; banks had to be compliant with Basel II, including operational risk early on. If ever there was a topic in finance made for me, it is this one.

Christian: How so?

Paul: The models you use in this context are very different from standard finance and in fact closer to insurance. Operational risk modelling is based on a very complicated data structure. Losses are classified into a 7×8 matrix, say, by loss type and business line, with very inhomogeneous and scant data, and extremely long tailed. I began stressing to the regulators

that there is no way you can treat operational risk in as successful a way as we have done with some of the other risk types, especially market risk. Eventually, the Advanced Measurement Approach to operational risk was dropped out of the Basel guidelines, and that's the current situation.

Christian: Would you say that operational risk is still a burning issue?

Paul: Eminently! The losses coming out of the financial crisis were so massive, so legally determined; after the 2008 financial crisis, they became a most important risk category. With Valérie and Marius, we recently got real data and designed a method, an inhomogeneous covariate driven Peaks-over-Threshold, for analysing operational risk type data (Chavez-Demoulin *et al.*, 2016). Marius and Valérie also developed very good software. It will not fully solve the problem in practice, but it makes sense if a company has good internal data to at least look at them with these methods. And indeed, I was recently called by an American company that started to use it.

Johanna: You mention the 2008 financial crisis. How did it affect you as an academic?

Paul: I was academically really in the heat of the discussion, but luckily never directly targeted and seriously attacked like colleagues in France.⁵ It was a very difficult period for mathematical finance. There was this paper by Salmon (2012) on 'the formula that killed Wall Street'. I defended mathematics fiercely, trying to explain how good mathematics is even more important after the crisis than before. The main argument is very nicely summarised in a *Forbes* interview with Steven Shreve (2008) from Carnegie Mellon University, who said 'the way out of our present dilemma is not to blame the quants. We must instead hire good ones – and listen to them'.

Christian: Did your work on Hawkes processes start about then as well?

Paul: Yes, this is another topic which became a major thread in my work. It started with Alex McNeil, Valérie Chavez and Anthony Davison (Chavez-Demoulin *et al.*, 2005). We looked at Hawkes process modelling of financial time series and at VaR and expected shortfall estimation. However, self-exciting point processes are very difficult mathematically, so progress was slow until Alex and I had an excellent student, Thomas Liniger, who had the right capacity to deal with the challenge and wrote a PhD thesis on how to encrypt the whole theory of Hawkes processes to make it adaptable to maximum likelihood estimation (Embrechts *et al.*, 2011). His thesis became one of the most downloaded at ETH, which says a lot! Then again I let it rest until I met Matthias Kirchner, who was my last PhD student. He was in a special situation, with a job in education and half grown-up children, but in the end, I convinced him to do a PhD; and so he did, absolutely brilliantly, on Hawkes processes. Serious mathematical work, and a committee to match, with Valérie Chavez, Thomas Mikosch and Alan Hawkes himself. Matthias got a silver medal from ETH, which is a high distinction for PhD theses. I am very proud of our joint paper on Hawkes graphs (Embrechts & Kirchner, 2018).

9 Outreach and Outlook

Johanna: During your career, you had many invitations to give talks at a variety of venues. Notably, you were the keynote speaker at four ASTIN Colloquia. What is your secret to good communication?

Paul: To start with, you have to like to talk and convey ideas to people! Then I would say scientific honesty, staying on your turf, and taking your audience seriously. Look at the audience: you'll see when you are off mark, and more importantly, you'll feel when people are getting interested. Then of course there are tricks to structuring your lecture: a bit of a surprise

moment, building up some tension, falling in with an open door and taking the audience by the hand right after again. One of my first general talks was addressed to some of the top people at Swiss Re, actuaries, lawyers, economists from all over the world. I asked: ‘If I were to ask you what is your favourite piece of music, I am sure you would know. If I were to ask you what is your favourite painting, you would also be able to say something. But now I’m asking you what is your favourite mathematical theorem?’ – silence. Then I went ‘here is mine’ and flashed the precise mathematical formulation of Itô’s lemma. A final piece of advice I would have is to prepare well, but not to over-prepare; otherwise, you’ll go to automatic mode. You need the adrenaline of the slight unpreparedness!

Christian: Speaking of adrenaline, you received your first honorary degree at 54, which is remarkable.

Paul: This was at the University of Waterloo in 2007, and it meant a lot to me given that it is one of the top actuarial schools in the world!⁶ I know how difficult it is to push for honorary degrees, so I am deeply grateful for this enormous honour which was bestowed upon me not just once, but four times, by top universities. Later came Heriot-Watt, Université catholique de Louvain, and City, University of London. I feel extremely flattered.

Christian: I see that you are now involved with the Risk Center at ETH. Does it relate to RiskLab?

Paul: The Risk Center started in 2011, and I was one of the co-founders. If you talk about risk, then everybody has his or her taking on the research and analysis of risk – not just mathematicians but also engineers, economists, people from the social or environmental sciences and so on. Initially, Hans-Jakob Lüthi and I thought we need a platform where we can discuss



From left to right: Hans Bühlmann, Paul Embrechts and Harry Panjer after convocation at the University of Waterloo, 15 June 2007.

risk, related to teaching and research projects beyond insurance and finance, making it really interdisciplinary. In that sense, it is separate from RiskLab, which in its current form focuses on the mathematical aspects of risk within actuarial science. Our first try failed, but the second attempt with more colleagues from engineering on board succeeded. By now, we have eight ETH departments involved. There is a lot happening there. The initiative is again supported by industry, although not in the same way as RiskLab. We have corporate partners that support us financially; we discuss potential projects and important issues for industry, but a financial support for a postdoc or PhD can only be given if two professors from different departments co-supervise. That's how I now have one project with an economist and two with civil engineers. The Center really established a platform for interdisciplinary research in the world of risk.

Johanna: In your career, you have done quite a bit of interdisciplinary work. How did you manage not to get caught between two stools?

Paul: Presumably, I did get caught occasionally. This is an important challenge I am very well aware of. Gerda still asks me occasionally 'where do you feel most at home academically?' I don't even have a full answer to that, although the basic field for me was and remains mathematics. I could not exist in a business school; I need mathematics around me, and I follow its broad progress. It was exciting to meet so many mathematical giants when the International Congress of Mathematicians was held in Zürich during my department chairmanship in 1994. Recently, I quite enjoyed reading the solution by Maryna Viazovska to the sphere packing problem in dimensions 8 and 24, out of interest, and I felt I really learned something new. It's that kind of link to mathematics that fascinates me. I also tell my students 'you are mathematicians; don't try to sell yourself differently: dive into one discipline and show that you are good at that'. However, I always encourage interdisciplinary thinking in my students. Interdisciplinary work per se will then come later when you grow older and have more freedom in the kind of problems you work on. I also very much push the students to come up with tangible results, that is, programmable – not only mathematical theorems, but results that work in a practical environment. To do this, you really have to understand it.

Christian: You have supervised nearly 40 PhD students and 40 postdocs during your time at ETH. How did you manage that?

Paul: One element is of course the positions, and there I was very lucky. As professors at ETH, we get PhD positions as compensation for teaching. Then some years ago, ETH also gave me two postdoc positions until my retirement; I could also get extra funds later as a senior Swiss Finance Institute professor. Beyond that, a number of PhD and postdocs were supported by industry, through RiskLab, the Risk Center and my own contacts. For example, Michel Dacorogna and I had two PhD students working part-time at SCOR, a reinsurance company and part-time here with me.

Johanna: How do you find topics?

Paul: I try to do that by extracting interesting mathematical research problems from questions that come to me from industry. It is very important to me that this stays well balanced, that is, relevant for practice but interesting mathematically. Then I had fruitful co-supervisions, too; for example, Johanna Ziegel, who is now a professor in Bern. She was interested in stochastic geometry and its applications in stereology, so I put her in touch with Eva Vedel Jensen in Aarhus. Later, she got interested in the world of risk and started working on elicibility, which we discovered from the writings of Gneiting and brought to the forefront in questions concerning the backtesting of expected shortfall and VaR estimators.

Christian: And what is your strategy for hiring postdocs?

Paul: Typically, I write directly to my academic contacts asking for good candidates. This works well most of the time. Then when they come, I let them free; I never say that they have to do a specific project, nor even publish papers together. Rather, I create an atmosphere such that if they want to work together, fine, if not, also fine.

Johanna: You have always been extremely supportive of your PhD students and postdocs. What would you say are the key elements of a supportive environment?

Paul: There is an interesting story there. When you were at ETH, I was still in my office on G-floor. A student, Michael Studer, now a successful chief risk officer of Partners Group, wrote a fantastic thesis with me but clearly wanted to go to industry. When he left, I asked how was his time at ETH. He replied ‘wonderful, fantastic research, but I missed the social component’. I went home and told Gerda: ‘Listen, I had this student and he missed that particular aspect. We have to do something about it’. So we started more social activities: RiskLab walks and later the Sola relay race. I gradually built up a more socially cohesive group and – this was extremely important and non-trivial – I moved my office from G-floor to RiskLab. This made all the difference. Then of course it also relies on people's initiative like you, Johanna, or Johanna Ziegel and Parthanil Roy. The secretarial support means a lot, too: the RiskLab secretaries even send birthday wishes to past and present members, so we maintain a bit of that friendship and family spirit together.

Christian: As a visitor at the *Forschungsinstitut für Mathematik* (FIM), I was also struck by the cordial and collegial atmosphere in the department.

Paul: Indeed, RiskLab is part of the larger ‘Group 3’ in the department, which consists of probability, finance and insurance. We have coffee and cake every Friday after lunch during the term. There, ETH helps. Now we also have a common room, on the advice of a visiting committee. People are not hiding behind their desk à la ‘leave me alone’. There is an overall welcoming atmosphere, with Christmas parties, walks, FIM coffee, etc. Everyone in the department can apply to FIM for visiting positions like you had, Christian, on several occasions; it is an important glue.

Johanna: Looking ahead, how do you see actuarial science evolving in the machine learning era?



From left to right: RiskLab Professors Alois Gisler, Paul Embrechts, Hans Bühlmann, Patrick Cheridito and Mario Wüthrich at ETH on 14 June 2019. Photo credit: Bastian Bergmann.

Paul: Back in the 1980s, I was already keenly aware of the power of data analytic tools with my work on CART, but machine learning techniques go well beyond that and could be a game changer. Some say that the traditional actuarial profession is under threat and that computer scientists are infringing on the field. An executive of an insurance company recently wrote: ‘We don’t need actuaries any more; we need data scientists’. I was horrified. This view needs to be fought vigorously, and it will be a challenge for the new generation to stand its ground. Actuarial work was always data driven and moved by questions of societal importance in developing models and insurance solutions for the benefit of the policyholders. Bagging, boosting, random forests and all sorts of ensemble learning techniques can be very useful, but of course, it will be Mario’s challenge and that of my successor, Patrick Cheridito, to address these issues. Together with Josef Teichmann, they are already well under way with research on deep learning in hedging, pricing or whatever. It’s totally exciting!

Christian: And what is your view on personalised insurance?

Paul: I stand alongside my predecessor, Hans Bühlmann, on this one. Fundamentally, it is not a reform I would like to see. There is a social aspect to insurance where we stand together and compensate each other’s risk. Someone from Swiss Re once told me that there are thousands of health apps out there that can be used to gather data about your personality, your habits, your behaviour. I find that frightening and suddenly find myself very conservative in a fast changing world. Yet the biggest mistake we could make as academics is to neglect such developments. We need to bring mathematical thinking to this area, and to stand our ground. It’s not that easy to do – and here I point to my younger colleagues who will have to shed light and provide actuarial guidance on continuous time monitoring, self-driving cars and a host of incredibly special products that are constantly being developed. Machine learning algorithms can be frightfully efficient, but there remains a need for meaningful modelling and validation. By explaining how models work, we can help to educate and raise awareness. Separating the wheat from the chaff requires skill, and principles, and there is a clear need for mathematics and statistics in this endeavour.

Johanna: And beyond work? How do you manage a healthy balance between your work and your personal life? What do you like to do when you don’t do mathematics?

Paul: I would never have been able to achieve what I did without my wonderful family and my wife Gerda, who has always been extremely dedicated to our children and supported me very much in all these international duties and talks I had to give; with the years, she accompanied me more and more, too. I could not have done all that without her backing. Although my family realises I have done important work, I am very glad that they keep my feet firmly on the ground and don’t carry me on an academic cloud. But a work-life balance is difficult; career is important but be careful not to overdo it. In hindsight, I should have made up more free time for the family, and I hope to have achieved that better now at a higher age. I help Gerda more and more now with babysitting our grandchildren, and we take many, almost daily, walks. I also love to read a lot, and to travel – so far mostly for work – but both Gerda and I very much like Asia (Singapore, Hong Kong, Vietnam) and had a wonderful time in the Kruger Park in South Africa. When the environment is right and the music is good, it is very hard to keep me off the dancing floor. Gerda is an extremely good dancer; she compensates for my randomness very well.

Christian: What are your plans for retirement?

Paul: There will for sure be some travelling. I will continue to try and convey our mathematical work in countries in Africa and Asia, and I have a visiting professorship in Hong Kong lined up. I also have a 3-year mandate at ETH, one day a week, to support the Risk Center and RiskLab, and links with industry. However, to give you an honest answer, my eye problems seriously worsened shortly before my retirement, and because of the medical situation, I haven’t



Paul Embrechts, his wife Gerda Janssens and their entire family at their home on 4 January 2020.

had time to really sit down with Gerda to see how we can enjoy this wonderful life. Many of my friends say ‘retire and do something completely different’. I don’t think I would be able to. Mathematics has been too much part of me. I have several ideas in the area of robust risk allocation, and this will surely keep me busy. Then there is a major plan to write a book with Valérie Chavez and Marius Hofert – if they are happy to follow along – on public communication and understanding of risk. In it, I want to talk about my personal experiences, my own point of view.

Christian & Johanna: It will be a treat! Thanks so much for this interview.

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Data Availability Statement

In recent years, Paul Embrechts has expressed views on a number of topics. The interested reader or true fan could consult, for example, Embrechts (2007), Bucher (2011), Leong (2012), Padovani (2013), Durante *et al.* (2015), Romeike & Scherer (2016), Hernández (2017), Scherer (2018) and Barrieu (2020). His ETH farewell lecture, on 30 May 2018, is also available at <https://math.ethz.ch/news-and-events/news/d-math-news/2018/05/paul-embrechts-farewell-lecture.html>.

Notes

¹Omer Weyenberg published books about mathematical drawing; see, for example, Weyenberg (1973).

²For more about Vervaat's life, see Maassen & Steutel (1996).

³A reference both to the 2008 financial crisis and the book by Nassim Nicholas Taleb (2007).

⁴For ample evidence to this effect, see Genest *et al.* (2009).

⁵See, for example, French Prime Minister Michel Rocard's comment in the edition of *Le Monde* dated 2–3 November 2008, and the academic response of Kahane *et al.* (2009).

⁶As documented, for example, in Genest & Carabarin-Aguirre (2013).

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