QRM, Extremes, Mathematics and the Financial Crisis

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About the title

I want to discuss with you four concepts:

Concept 1: QRM
Concept 2: Extremes (low probability events)
Concept 3: Mathematics
Concept 4: Financial Crisis

From a (somewhat personal) historical perspective and in the light of the current economic crisis.

Some relevant examples

- February 1, 1953: Dutch dyke disaster
- January 28, 1985: Challenger explosion
- October 19, 1987: Black Monday
- July 6, 1988: Piper Alpha
- January 17, 1994: Northridge Earthquake
- January 17, 1995: Barings and Kobe
- September 1998: LTCM hedge fund crisis
- 2007-200x (x>9!): Credit crisis
- and (unfortunately) many more …
(February flooding)

- 1836 people killed
- 72000 people evacuated
- 49000 houses and farms flooded
- 201000 cattle drowned
- 500 km coastal defenses destroyed; more than 400 breaches of dykes
- 200000 ha land flooded
The Delta – Project

- Coastal flood-protection
- Requested dyke height at l: \( h_d(l) \)
- Safety margin at l: \( \text{MYSS}(l) = \text{Maximal Yearly Sea Surge at } l \)
- Probability(\( \text{MYSS}(l) > h_d(l) \)) should be “small“, whereby “small“ is defined as: (Risk)
  - 1 / 10000 in the Randstad
  - 1 / 250 in the Deltaregion in the North
  - Similar requirements for rivers, but with 1/10 – 1/100
- For the Randstad (Amsterdam-Rotterdam):
  Dyke height = Normal-level (= NAP) + 5.14 m
Guus Balkema
Ex.2: Northridge Earthquake: some loss ratio numbers (%) to think about!

<table>
<thead>
<tr>
<th>Year</th>
<th>Loss Ratio (%)</th>
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<tbody>
<tr>
<td>1971</td>
<td>17.4</td>
</tr>
<tr>
<td>1972</td>
<td>0.0</td>
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<tr>
<td>1973</td>
<td>0.6</td>
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<td>1974</td>
<td>3.4</td>
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<td>1975</td>
<td>0.0</td>
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<td>1976</td>
<td>0.0</td>
</tr>
<tr>
<td>1977</td>
<td>0.7</td>
</tr>
<tr>
<td>1978</td>
<td>1.5</td>
</tr>
<tr>
<td>1979</td>
<td>2.2</td>
</tr>
<tr>
<td>1980</td>
<td>9.2</td>
</tr>
<tr>
<td>1981</td>
<td>0.9</td>
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<tr>
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<tr>
<td>1994</td>
<td>2272.7</td>
</tr>
</tbody>
</table>

Isoseismal map for the Northridge earthquake. Roman numerals denote an average intensity within the shaded areas; intensities at individual communities are often one intensity unit higher or lower than the regional average value depicted by the map.
Fin-Ex.1: February 1995

THE COLLAPSE OF BARINGS

Stephen Fay
The Great Hanshin (Kobe) earthquake of January 17, 1995

Prime example for Operational Risk, external event (on top of all else)
How Kobe earthquake and a straddle position finally broke the back of Barings bank

Straddle = Short Call and Short Put on Common Strike

Volume of Nikkei Futures
Fin-Ex.2: The Black-Scholes Formula(s)

\[ c = S_0 \, N(d_1) - K \, e^{-rT} \, N(d_2) \]
\[ p = K \, e^{-rT} \, N(-d_2) - S_0 \, N(-d_1) \]

where

\[ d_1 = \frac{\ln(S_0 / K) + (r + \sigma^2 / 2)T}{\sigma \sqrt{T}} \]
\[ d_2 = \frac{\ln(S_0 / K) + (r - \sigma^2 / 2)T}{\sigma \sqrt{T}} = d_1 - \sigma \sqrt{T} \]
Financial Derivatives: *where (*) it all started (*)*

- However (*), L. Bachelier (1900), V. Bronzin (1908), E.O. Thorp (1969)!
The Black-Scholes Model and **Model Uncertainty**

Just waiting for **the storm** to hit!
And the **Perfect Storm** came in September 1998

![Nobel Prize 1997](image)

Some vivid recollections of meetings/discussions with RM and MS:

- 1996: Meetings with RM and MS selling LTCM investment to Swiss Private Banks
- 1996-1998: Several discussions with MS on the use of EVT to calculate (market) regulatory capital: “Who is going to pay for the difference?”, i.e. $\Delta = (\text{VaR-EVT}) - (\text{VaR-Normal}) >> 0$
- Cambridge Newton Institute Workshop on Managing Uncertainty, 2001: “Insurance is (just) the other side of the coin (of finance)!” (MS)
- Copula confusion
What about regulation?

- 1988: Basel I
- 1994 – 2000: Amendment to Basel I (Basel I ½), Value-at-Risk (VaR) is born
- 2000 – 2009/10(?): Basel II (Credit and Operational Risk)
- Future: Basel III ???
- Later more on this!
What we should have learned from these and similar events:

• One (past) example:
  - The Challenger explosion
and then more on the current issue:
  - The credit crisis …
Lesson 1: A (very) brief discussion on the Challenger explosion

Richard Feynman

[Diagram: NASA Space Shuttle O-Ring Failures]
Some key modeling input:

- Logistic regression: theory exists!
- Rare event prediction (31 degr. F)
- Model Uncertainty
- Statistical analysis: data matters!
- Statistical estimation of this uncertainty (95% confidence intervals)
  
  These intervals are typically very wide for the estimation of rare events
**Lesson 2: A (very) brief discussion on the credit crisis**

The players (the agents, the components, the jigsaw pieces) (from Crouhy, Jarrow, and Turnbull (2008)):

- Rating Agencies
- Mortgage Brokers and Lenders
- Special Investment Vehicles (SIVs)
- Monolines
- ABS Trust, CDS, CDO and CDO Squared Equity Holders
- Financial Institutions
- The Economy and Central Banks
- Valuation Uncertainty … once again!!!!
- Transparency, or better… Opaqueness!
- Systemic Risk
- Politicians/the press/lawyers/accountants/the public …

All of these “components” need a careful and in depth discussion!
As examples of credit derivatives:

**CDS** = Credit Default Swap
A relatively simple instrument

**CDO** = Collateralized Dept Obligation
A rather complex instrument

A brief technical discussion of the latter and a somewhat more general discussion on the former:
“There is growing recognition that the dispersion of credit risk by banks to a broader and more diverse group of investors, rather than warehousing such risk on their balance sheets, has helped make the banking and overall financial system more resilient.

The improved resilience may be seen in fewer bank failures and more consistent credit provision. Consequently the commercial banks may be less vulnerable today to credit or economic shocks.”

IMF Global Financial Stability Report, April 2006
A stylized Credit Default Swap Set-Up

1 bio USD

1%/year

Insurance on F-BB’s debt

10%/year

rating

10% yearly Insurance on F-BB’s debt

PF1

F-BB

IC-AA

PF2/F2

PF3/F3

PFn/Fn

RA

HF1

HFk

rating

rating

default, no link

Betting on default, no link
Complexity, Opacity, Distance, Greed, Economic and Political Stupidity, Regulatory Blindness, Academic Naivety, and Arrogance

We are all to blame!
A sure road for disaster

• In the previous picture, problems occur if several corporations default at the same time, in that case the insurance companies have to pay, may loose their high rating causing the pension funds (investors) more problems, etc, etc … someone at some time will blame the rating agencies

• But what about the hedge funds … ?

• In the end all depends on default correlation … enters the Gauss-copula.
Impact of dependence on loss distribution

Distribution of number of defaults for homogeneous portfolio of 1000 BB loans with default probability $\approx 1\%$; Bernoulli mixture model with default correlation $\approx 0.22\%$ is compared with independent default model.

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CDOs - Basic Structure

There are a variety of CDO contracts, but all have the same basic structure. Each CDO has a asset side, and a liability side, linked by a special purpose vehicle (SPV).

- The assets consist of credit risky securities related to a pool of reference entities; typically bonds, loans or - in synthetic CDOs - a protection-seller positions in single name CDS.

- These assets are acquired by the SPV. To finance the asset purchase the SPV issues notes. This amounts to a repackaging of the assets.

- The notes form the liability side of the structure. They belong to tranches of different seniority, called senior, mezzanine and equity piece. Due to repackaging most losses of the assets are borne by the equity piece, and the credit rating of mezzanine and senior tranches is higher than average rating of asset pool.
(Synthetic) CDOs - Basic Structure

Payments in a CDO structure; above arrow: asset-based structure; below arrow: synthetic CDO.

Credit Default Swaps

Securitisation construction

The investors

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**Synthetic CDOs: Payment Description**

**Notation.** Consider portfolio of $m$ loans with nominal $e_i$, relative LGD $\delta_i$ and default-indicator process $(Y_t)$. Cumulative loss of the portfolio in $t$ given by $L_t = \sum_{i=1}^{m} \delta_i e_i Y_{t,i}$.

**The CDO.** Maturity $T$. We have $k$ tranches, characterized by attachment points $0 = K_0 < K_1 < \cdots < K_k \leq \sum_{i=1}^{m} e_i$. The notional of tranche $\kappa$ at time $t$ is given by

$$N_{\kappa}(t) = f_{\kappa}(L_t) \text{ with } f_{\kappa}(l) = \begin{cases} K_{\kappa} - K_{\kappa-1} & \text{for } l < K_{\kappa-1} \\ K_{\kappa} - l & \text{for } l \in [K_{\kappa-1}, K_{\kappa}] \\ 0 & \text{for } l > K_{\kappa} \end{cases}.$$

Note that $f_{\kappa}(l) = (K_{\kappa} - l)^+ - (K_{\kappa-1} - l)^+$ (put spread with strike prices $K_\kappa$ and $K_{\kappa-1}$).
Payments of a Synthetic CDO

Consider CDO with attachment points $K_0 < \cdots < K_k$ and notional of tranche $\kappa$ given by $N_\kappa(t) = (K_\kappa - L_t)^+ - (K_{\kappa-1} - L_t)^+$; define cumulative loss of tranche $\kappa$ as $L_\kappa(t) := N_\kappa(0) - N_\kappa(t)$.

**Default payments of CDO.** Default payment of tranche $\kappa$ at $n$th default time $T_n < T$ given by $\Delta L_\kappa(T_n) = (L_\kappa(T_n) - L_\kappa(T_{n-1}))$ (the part of cumulative loss at $T_n$ falling in the layer $[K_{\kappa-1}, K_\kappa]$).

**Protection fee or premium payments.** Holder of tranche $\kappa$ receives periodic premium payments at $0 < t_1 < \cdots < t_N = T$ of size $x_\kappa^{\text{CDO}}(t_n - t_{n-1})N_\kappa(t_n)$. No initial payments. $x_\kappa^{\text{CDO}}$ is called the (fair) CDO spread.
A stylized Example

**Stylized CDO.** We assume that payoff of tranche $\kappa$ is simply given by $N_{\kappa}(T)$, the value of the notional at maturity. Real CDOs are more complicated, as there is intermediate income, but stylized example retains essential features.

**Impact of default dependence.** More dependence, same marginal default probabilities $\Rightarrow$ Equity tranche increases in value, senior tranches decrease in value. Impact on mezzanine tranches unclear.

Qualitative properties carry over to more complex structures actually traded.
Default Correlation and CDO Tranches

The waterfall principle

Payoff of a stylized CDO with attachment points at 20, 40 and 60 with two different loss distributions overlayed.

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An import critical voice:

Warren Buffet on Derivatives (Berkshire Hathaway annual report for 2002):

The derivatives genie is now well out of the bottle, and these instruments will almost certainly multiply in variety and number until some event makes their toxicity clear. Central banks and governments have so far found no effective way to control, or even monitor, the risks posed by these contracts. In my view, derivatives are financial weapons of mass destruction, carrying dangers that, while now latent, are potentially lethal.
Some dimensions before we continue:

Thousand $ = 1 000 $  
Million $ = 1 000 000 $  
Billion (US) $ = 1 000 000 000 $  
  = 1 Milliard (UK) $  
Trillion (US) $ = 1 000 000 000 000 $  
  = 1 Billion $ (UK)  
  = 1 Billion $ (Germany)  
Trillion (UK) $ = 1 000 000 000 000 000 000 $  

Everything clear … I hope.
50 000 000 000 000 $ *

- CDS is almost a brand new investment vehicle, but the market is already 20 times its size in 2000. The principal amount of CDS outstanding equals $50 trillion, or more than three times the U.S. Gross Domestic Product and bigger than all the U.S. credit markets put together. And the CDS has been a huge source of "financial engineering" profits, both for Wall Street and the hedge fund community over the last few years.
- World GDP is about $66 trillion.
- First CDS about 1995.
- Total nominal volume of OTC derivatives 550 Tri. $ 

* 3.7 Tri. $ after netting
The basic copula construction ($d = 2$)

\[ C_{X,Y}(u, v) \]

\[ F_X(x), F_Y(y) \]

\[ F_{X,Y}(x, y) = C_{X,Y}(F_X(x), F_Y(y)) \]
Distribution Functions A-B

Copula (Verteilungsfunktion)
This paper studies the problem of default correlation. We first introduce a random variable called "time-until-default" to denote the survival time of each defaultable entity or financial instrument, and define the default correlation between two credit risks as the correlation coefficient between their survival times. Then we argue why a copula function approach should be used to specify the joint distribution of survival times after marginal distributions of survival times are derived from market information, such as risky bond prices or asset swap spreads. The definition and some basic properties of copula functions are given. We show that the current CreditMetrics approach to default correlation through asset correlation is equivalent to using a normal copula function. Finally, we give some numerical examples to illustrate the use of copula functions in the valuation of some credit derivatives, such as credit default swaps and first-to-default contracts.
The Gauss-Copula (d=2)

In the two-dimensional case with correlation parameter $\rho$

$$C^\Phi(a,b) = \Phi_2(\Phi^{-1}(a), \Phi^{-1}(b); \varrho) =$$

$$\int_{-\infty}^{\Phi^{-1}(a)} \int_{-\infty}^{\Phi^{-1}(b)} \frac{1}{2\pi \sqrt{1-\rho^2}} \exp \left( \frac{2\rho uv - u^2 - v^2}{2(1 - \rho^2)} \right) du dv$$

And with density function

$$c^\Phi(a,b) = \exp \left( \frac{(\Phi^{-1}(a))^2 + (\Phi^{-1}(b))^2}{2} + \frac{2\rho \Phi^{-1}(a) \Phi^{-1}(b) - (\Phi^{-1}(a))^2 - (\Phi^{-1}(b))^2}{2(1-\rho^2)} \right) \sqrt{1-\rho^2}$$

Let us call the Gauss-Copula the normal-copula!
Two results from the 1998 RiskLab report

CORRELATION AND DEPENDENCE IN RISK MANAGEMENT:
PROPERTIES AND PITFALLS

PAUL EMBRECHTS, ALEXANDER MCNEIL, AND DANIEL STRAUMANN

Remark 1: See Figure 1 next page

Remark 2: In the above paper it is shown that

Thus the Gaussian copula gives asymptotic independence, provided that \( \rho < 1 \). Regardless of how high a correlation we choose, if we go far enough into the tail, extreme events appear to occur independently in each margin. See Sibuya (1961) or Resnick (1987), Chapter 5, for alternative demonstrations of this fact.
Figure 1. 1000 random variates from two distributions with identical Gamma(3,1) marginal distributions and identical correlation $\rho = 0.7$, but different dependence structures.
The Gauss-copula model caused a first strong breeze:

September 12, 2005

How a Formula Ignited Market That Burned Some Big Investors
The model Mr. Li devised helped estimate what return investors in certain credit derivatives should demand, how much they have at risk and what strategies they should employ to minimize that risk. Big investors started using the model to make trades that entailed giant bets with little or none of their money tied up. Now, hundreds of billions of dollars ride on variations of the model every day.

"David Li deserves recognition," says Darrell Duffie, a Stanford University professor who consults for banks. He "brought that innovation into the markets [and] it has facilitated dramatic growth of the credit-derivatives markets."
David Li warned himself early on:

The problem: The scale's calibration isn't foolproof. "The most dangerous part," Mr. Li himself says of the model, "is when people believe everything coming out of it." Investors who put too much trust in it or don't understand all its subtleties may think they've eliminated their risks when they haven't.

David X. Li in Wall Street Journal Article, 2005.
But then the **Perfect Storm** struck (again)!
The Bear Stearns Companies, Inc. (BSC)
On Mar 14: BSC Closed at $30.00 down $27.00 (47.37\%)
Market Cap: $4.08B
Trailing P/E (ttm, intraday): 19.70
Forward P/E (fye 30-Nov-09) 1: 3.34
PEG Ratio (5 yr expected): 0.45
Price/Sales (ttm): 1.31
Price/Book (mrg): 0.68

Bogus Balance Sheet
Total Cash (mrg): 266.94B
Total Cash Per Share (mrg): 1,960.529
Total Debt (mrg): 229.456B
Total Debt/Equity (mrg): 19.457
Current Ratio (mrg): 1.17
Book Value Per Share (mrg): 84.03

Sunday March 16, 2009: J.P. Morgan Chase buys Bear Stearns for $2 a share in a stock-swap transaction that values BSC at just $236 million
And once more, the popular press blamed the mathematicians, the quants, through the Gaussian-(normal-){\textit{copula}}, for having blown up the economy!
Numerous newspaper articles:


• The *Financial Times*, Sam Jones (April 24, 2009), *On Couples and Copulas*

• Steve Lohr, September 12, 2009, *NY Times*, *Wall Street’s Math Wizards Forgot a Few Variables*

• ...
Recipe for Disaster: The Formula That Killed Wall Street
By Felix Salmon 23 February, 2009
Wired Magazine

\[
\Pr[T_A < 1, T_B < 1] = \phi_2(\phi^{-1}(F_A(1)), \phi^{-1}(F_B(1), \gamma))
\]
The popular press is full of statements like:

- From risk-free return to return-free risk
- Mark-to-market, mark-to-model, mark-to-myth
- Here’s what killed your 401(k)
- Mea Copula
- Anything that relies on correlation is charlatanism (N.N.Taleb)
- Double defeat for Wall Street and Mathematics
- Rather than common sense, financial mathematics was ruling
- Etc …
In the autumn of 1987, the man who would become the world’s most influential actuary landed in Canada on a flight from China. He could apply the broken hearts maths to broken companies.

Li, it seemed, had found the final piece of a risk-management jigsaw that banks had been slowly piecing together since quants arrived on Wall Street.

Why did no one notice the formula’s Achilles heel?
Dear Sir

The article "Of couples and copulas", published on 24 April 2009, suggests that David Li's formula is to blame for the current financial crisis. For me, this is akin to blaming Einstein's $E=mc^2$ formula for the destruction wreaked by the atomic bomb.

Feeling like a risk manager whose protestations of imminent danger were ignored, I wish to make clear that many well-respected academics have pointed out the limitations of the mathematical tools used in the finance industry, including Li's formula. However, these warnings were either ignored or dismissed with a desultory response: "It's academic".

We hope that we are listened to in the future, rather than being made a convenient scapegoat.

Yours Faithfully,
Professor Paul Embrechts
Director of RiskLab
ETH Zurich
Some personal recollections on the issue:

28 March 1999
Columbia-JAFEE Conference on the Mathematics of Finance,
Columbia University, New York.
10:00-10:45  P. EMBRECHTS (ETH, Zurich):

"Insurance Analytics:
Actuarial Tools in Financial Risk-Management“

Why relevant?

Correlation and Dependence in Risk Management:

2. Coffee break: discussion with David Li.
If you are interested in my views on Copulas and QRM:

• Read my paper:
  “Copulas: A personal view”
See also my website:
www.math.ethz.ch/~embrechts
There were however several early warnings (1)

It Doesn’t Take Nostradamus

JOSEPH E. STIGLITZ


“I went on to explain how securitization can give rise to perverse incentives … Has the growth in securitization been result of more efficient transactions technologies, or an unfounded reduction in concern about the importance of screening loan applications? … we should at least entertain the possibility that it is the latter rather than the former.”

At the very least, the banks have demonstrated an ignorance of two very basic aspects of risk: (a) the importance of correlation, and (b) the possibility of price decline.
There were however several *early warnings* (2)

There were however several early warnings (3)

Markopolos, H. (2005): The world’s largest hedge fund is a fraud. (Mailed to the SEC)

(Madoff runs a Ponzi scheme)

Harry Markopolos  Bernard Madoff  Charles Ponzi 1910
1.1 (iv) **Misplaced reliance on sophisticated maths**

There are, however, fundamental questions about the validity of VAR as a measure of risk (see Section 1.4 (ii) below). And the use of VAR measures based on relatively short periods of historical observation (e.g. 12 months) introduced dangerous procyclicality into the assessment of trading-book risk for the reasons set out in Box 1A (deficiencies of VAR).

The very complexity of the mathematics used to measure and manage risk, moreover, made it increasingly difficult for top management and boards to assess and exercise judgement over the risks being taken. Mathematical sophistication ended up not containing risk, but providing false assurance that other prima facie indicators of increasing risk (e.g. rapid credit extension and balance sheet growth) could be safely ignored.

1.1 (v) **Hard-wired procyclicality:** …
1.4 (iii) Misplaced reliance on sophisticated maths: fixable deficiencies or inherent limitations?

Four categories of problem can be distinguished:

- Short observation periods
- Non-normal distributions
- Systemic versus idiosyncratic risk
- Non-independence of future events; distinguishing risk and uncertainty

This is the main reason why we make a difference between Model Risk and Model Uncertainty. We very much stress the latter!

Frank H. Knight, 1921
Supervisory guidance for assessing banks’ financial instrument fair value practices
April 2009, Basel Committee on Banking Supervision

• **Principle 8:** Supervisors expect bank valuation and risk measurement systems to systematically **recognise and account for valuation uncertainty.** In particular, valuation processes and methodologies should produce **an explicit assessment of uncertainty** related to the assignment of value for all instruments or portfolios. When appropriate this may simply be a statement that uncertainty for a particular set of exposures is very small. **While qualitative assessments are a useful starting point, it is desirable** that banks develop methodologies that provide, to the extent possible, **quantitative assessments.** These methodologies may gauge the sensitivity of value to the **use of alternative models and modelling assumptions** (when applicable), to the use of alternative values for key input parameters to the pricing process, and to alternative scenarios to the presumed availability of counterparties. The extent of this analysis should be commensurate to the importance of the specific exposure for the overall solvency of the institution.
Financial Mathematics and the Credit Crisis

“If Financial Mathematicians have an understanding of the derivative products at the root of the credit crisis, can they offer any insights on the current economic situation. Specifically, there is a sense of gloom that “The City is over” and is there a more positive view.”

(Question posed to researchers by Lord Drayson, the UK Science and Innovation Minister)
Some replies by researchers:

- *(L.C.G. Rogers)* The problem is not that mathematics was *used* by the banking industry, the problem was that it was *abused* by the banking industry. Quants were instructed to build models which fitted the market prices. Now if the market prices were way out of line, the calibrated models would just faithfully reproduce those wacky values, and the bad prices get reinforced by an overlay of scientific respectability!
And Rogers continues:

- The standard models which were used for a long time before being rightfully discredited by (some) academics and the more thoughtful practitioners were from the start a complete fudge; so you had garbage prices being underpinned by garbage modelling.

- (M.H.A. Davis) The whole industry was stuck in a classic positive feedback loop which no party could (P.E. “wanted to”) walk away from. Indeed only some!
EVT = Extreme Value Theory

EVT (first established around the 1920’s) offers a sound set of techniques for the understanding and statistical estimation of rare events, beyond the bell-curve world: it describes the statistical behavior of the largest observation, the biggest loss, the worst case, rather than the average observation, the average loss, the average case.

For details: see the following textbooks!
EVT has become a standard

Some examples (but there are many more)
A message for my students

New generations of students will have to use the tools and techniques of QRM wisely in a world where the rules of the game will have been changed.

Always be scientifically critical, as well as socially honest, adhere to the highest ethical principles, especially in the face of temptation … which will come!
And on the boundedness of our knowledge:

There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy!

William Shakespeare
(Hamlet I.v. 166)