Integrating ESG-Related Risks into ERM - A Risk Network Enhanced Analysis of Systemic Risks in the Food and Agriculture Sector

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[1] Appendix C.
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1. Introduction

Risks exhibit attributes that can be ordered into two main categories: volatility, and 'black swans'[4]. Volatility refers to the periods when they display 'random walk' stochastic behaviours or when they behave as if the underlying process is stationary. This characteristic of risk is a well-documented assumption in common paradigms within quantitative risk management[5] and receives widespread use in established and evolving risk management methodology research and practice[6]. These properties are, furthermore, straightforwardly accommodated in models used for corporate governance; capital adequacy calculations destined for board and board committees'[7] oversight, executive and C-Suite stewardship[8] as well as three or five lines of defence delineations. They are, ultimately, used to frame methods of regulatory supervision[9].

The second dimension of risk, memorably coined 'black swans'[10], refers to the unforeseen, unexpected predilection of risk to generate extreme consequences that are not only severely disruptive, but very costly[11]. This behaviour contradicts the claims of explanatory power for those traditional risk management tools and frameworks applied to risk when it appears to obey a stochastic process, has "reversion to the mean" and allows distributions to be fitted to the underlying data[12].

In the context of this perspective KPMG was requested by the World Business Council for Sustainable Development (WBCSD) to

> "Identify the risks and their mitigants towards not being able to feed a projected population of nine billion people"

2. Approaching the risk modelling

Recently published research[13] makes it clear that the macro-economic environment is characterised by phase transitions[14] generating structural breaks[15] and other dynamics that

[4] Massimo Massa: Rothchild Chaired Professor of Banking and Professor of Finance: INSEAD. Abu Dhabi: 10 February 2020.

[5] For example, strategic risk, compliance risk, market risk, liquidity risk and operational risk.

[6] Both quantitative and qualitative methodologies and ultimately into the software and tools used by organisations to manage risk.

[7] Board Audit Committees and Board Risk Committees.

[8] At executive level they include Asset Liability Committees, Treasury oversight, Executive Risk Committees, off site programs for the formulation of risk appetite and delegation authorities.

[9] Including self-imposed regulatory initiatives such as Basel.

[10] Taleb, N. H.: The Black Swan: The Impact of the Highly Improbable. Penguin Books: United Kingdom. London: 2007.

[11] Between $5.7 trillion and $13 trillion, according to Ferguson, N. In: The Square and the Tower. Networks, Hierarchies and the Struggle for Global Power. Penguin Random House: London. 2017.

[12] Sections 2, 3 and 4.

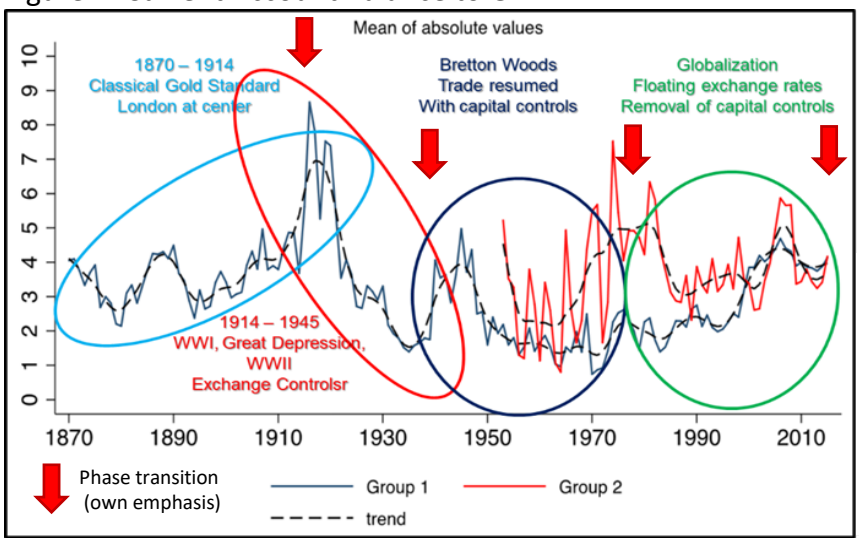
[13] Bordo, M. D.: The Second Era of Globalization Is Not yet Over: An Historical Perspective. Hoover Institution Economics Working Papers: Rutgers University, NBER, and the Hoover Institution, Stanford University. Economics Working Paper 17103. Hamburg, Germany: 3–4 July 2017.

[14] As perturbations are made to macroscopic variables of a system, its properties can change, abruptly, often in a dramatic way. Examples include water changing from a solid (ice) into a liquid and / or into a gas; metal becoming magnetised; material becoming watertight (or not); superconductivity and more.

[15] A shift in the dynamics of a time series, like the discovery of antibiotics, birth control pill, satellite communication, and containerisation. Some of the shifts may have been observed in different forms before, whilst other trends / developments / innovations may be

cause risk to be non-stationary[16]. Bordo[17] e.g. distinguished several phase transitions over the past 150 years of macro-economic history:

Figure 1: Current Account Balance to GDP

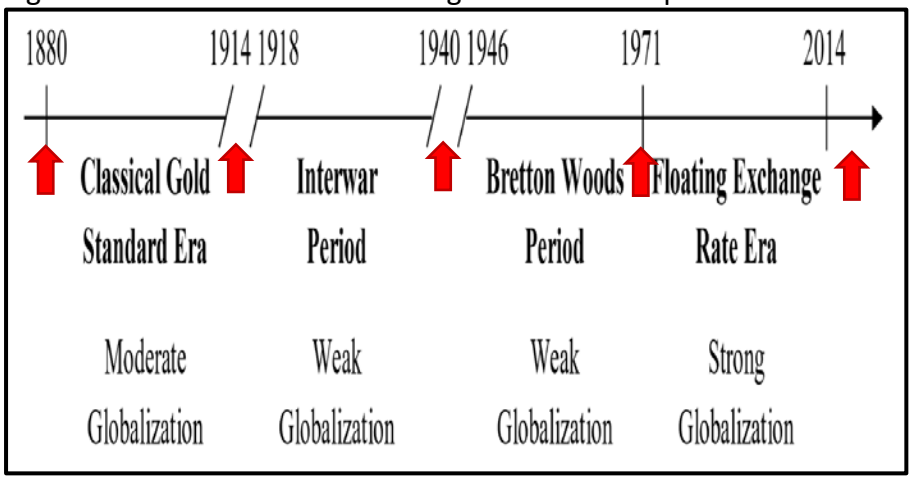


Source: Bordo, M. D.: The Second Era of Globalization Is Not yet Over: An Historical Perspective. Hoover Institution Economics Working Papers: Rutgers University, NBER, and the Hoover Institution, Stanford University. Economics Working Paper 17103. Hamburg, Germany: 3 – 4 July 2017. p.14.

Group 1: Argentina, Australia, Canada, Denmark, Finland, France, Germany Italy, Japan, Norway, Sweden, UK and USA
Group 2: Algeria, Brazil, Chile, China, Columbia, Egypt, Hungary, India, Israel, Korea, Malaysia, Mexico, Morocco, Pakistan, Peru, Philippines, Poland, Romania, South Africa, Thailand, Turkey and Venezuela
Note: trend estimated with HP filter
Sources: Jordà, Schularick & Taylor (2017), WB World Development Indicators (2017), IMF International Financial Statistics (2017)

Accominotti[18] et al. similarly identified macro-economic phase transitions:

Figure 2: Global Stock Market integration over the period 1880 – 2014



Source: Accominotti, O., Briere, M., Burietz, A., Oosterlinck, K. & Szafarz, A.: Did Globalization Kill Contagion? Centre for Economic Policy Research, London. 8 February 2020: p.4.

Phase transition
(own emphasis)

Phase transitions and structural breaks change the nature of change. Individually, and in combination, they forge unprecedented opportunities as well as their antitheses: non-stationary risks.

The non-stationarity of one such change is evident in the following depiction:

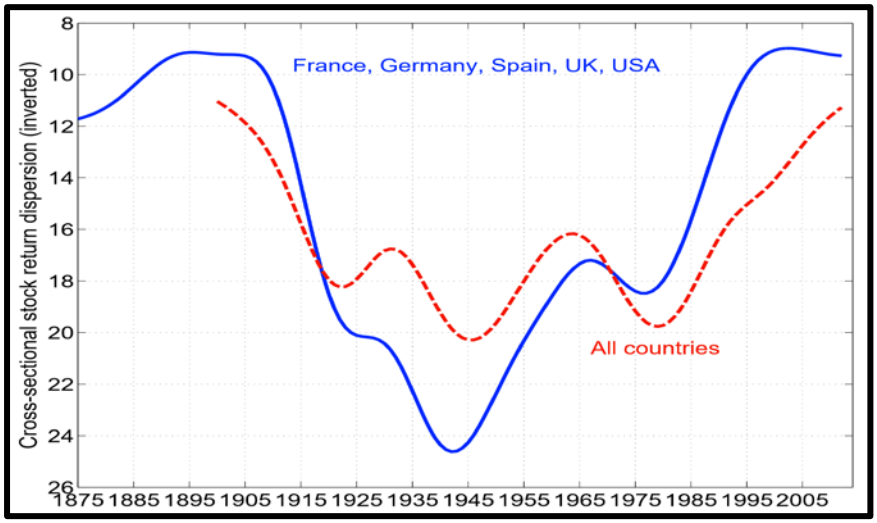
unprecedented to the extent that past data on their consequences, potential contagion, interactions and other downstream implications do not exist.

[16] Time stationarity implies that the statistics of a posited distribution for observe variables or residuals from a model are constant in time.

[17] *Supra* Note 13.

[18] Accominotti, O., Briere, M., Burietz, A., Oosterlinck, K. & Szafarz, A.: Did Globalization Kill Contagion? Centre for Economic Policy Research, London. 8 February 2020.

Figure 3: Stock Market Integration

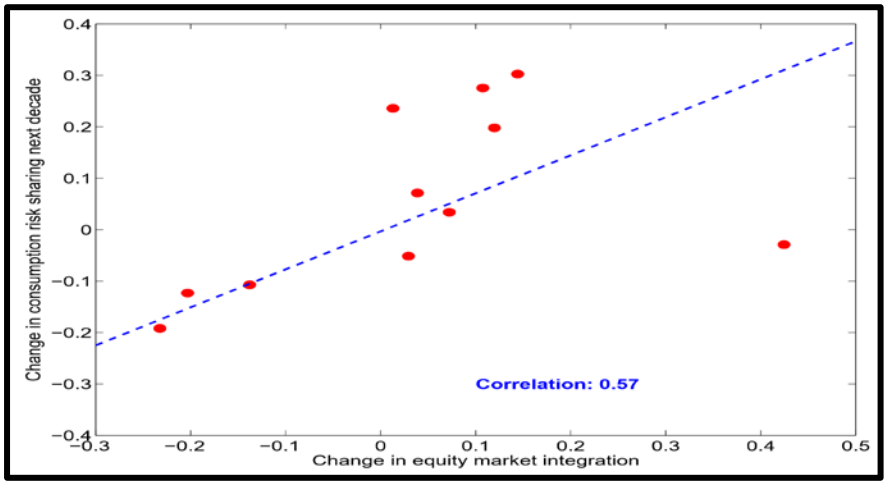


Source: Rangvid, J., Santa-Clara, P. & Schmeling, M.: Capital Market Integration and Consumption Risk Sharing over the Long Run. 12 Jan. 2016: p.43.

The consequences of the non-stationarity of change on risk received attention in a recent research paper[19] that identified the level of global integration over the last decade (Figure 3) to strongly predict the level of risk sharing for the next decade[20] with a R^2 of 24%[21]. The economic effect of risk sharing, measured over a decade, is "sizeable"[22] with a coefficient of 2.08[23].

In short, when global markets integrate, as they did from 1980 to 2016, the risk exposure from the previous decade doubles over the next decade:

Figure 4: Change in equity market integration's correlation with change in consumption risk sharing in the next decade



Source: Integration and Consumption Risk Sharing over the Long Run. 12 Jan. 2016: p. 45. Rangvid, J., Santa-Clara, P. & Schmeling, M.: Capital Market.

[19] Rangvid, J., Santa-Clara, P. & Schmeling, M.: Capital Market Integration and Consumption Risk Sharing over the Long Run. 12 Jan. 2016.

[20] Op. Cit.: p.16.

[21] Meaning that, decade on decade, 24% of the current variation in risk sharing can be explained by the level of integration in the previous one.

[22] *Supra* Note 20.

[23] *Supra* Note 22.

Consumption risk[24,25] sharing is defined as "idiosyncratic shocks to consumption [that] are diversified away and thus shared with other countries."[26]

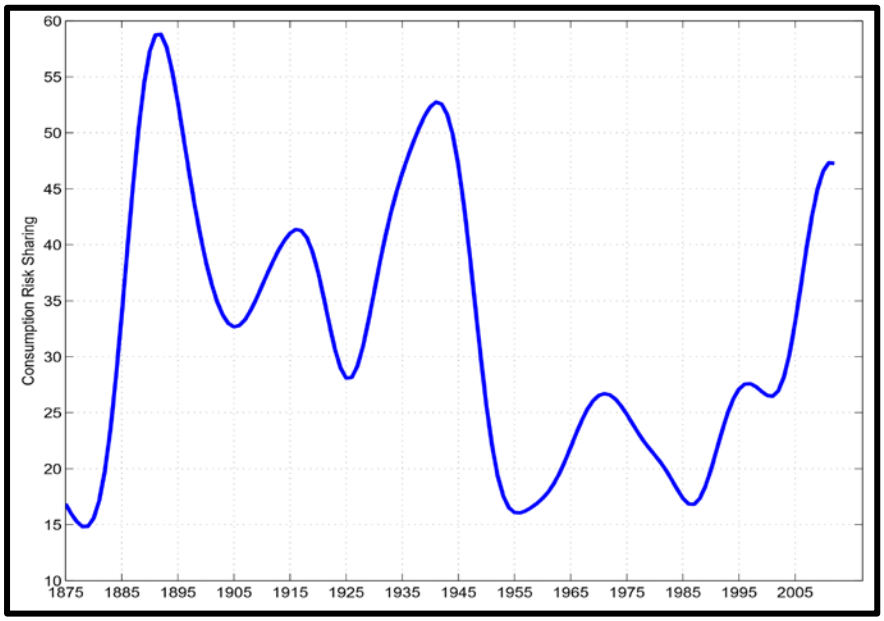
Rangvid et al. found a one standard deviation increase in globalisation to produce a 1.36 standard deviation multiplier in risk sharing over the next decade[27].

Risk, as a result, is *not constant*. It itself changes[28]. From Goetzmann[29] et al.:

> "…the structure of global correlations shifts considerably through time."

The non-stationarity of risk *per se* is apparent from Figure 5:

Figure 5: Consumption Risk Sharing



Source: Rangvid, J., Santa-Clara, P. & Schmeling, M.: Capital Market Integration and Consumption Risk Sharing over the Long Run. 12 Jan. 2016: p.41.

[24] Asdrubali, P., Sorensen, B.E. & Yosha, O.: 1996. Channels of interstate risk sharing: United States 1963 – 90. *Quarterly Journal of Economics* 111, 1081 – 1110; Sorensen, B.E. & Yosha, O.: 1998. International risk sharing and European monetary unification. *Journal of International Economics* 45, 211 – 238; Sorensen, B.E., Yosha, O., Wu, Y-T & Zhu, Y.: 2007. Home bias and international risk sharing: twin puzzles separated at birth. *Journal of International Money and Finance* 26 (4), 587 – 605; Kose, M., Prasad, E. & Terroes, M.: 2009. Does financial globalization promote risk sharing? *Journal of Development Economics* 2009, 258 – 270 extended the approach of Obstfeld, showing that the degree of consumption risk sharing can be estimated from a regression of deviations of own-country consumption growth ($\Delta c_{i,t}$) from world consumption growth ($\overline{\Delta c}_t$) on deviations of own-country growth ($\Delta y_{i,t}$) from world income growth ($\overline{\Delta y}_t$):

$$\Delta c_{i,t} - \overline{\Delta c}_t = \alpha + \beta(\Delta y_{i,t} - \overline{\Delta y}_t) + \varepsilon_{i,t}.$$

World growth is measured as consumption and income GDP-weighted averages across countries. β can be interpreted as a measure of the degree of consumption risk sharing: it quantifies the sensitivity of idiosyncratic consumption growth to changes in idiosyncratic income growth.

[25] Obstfeld, M. (Are industrial-country consumption risks globally diversified? In: Leiderman, L. & Razin, A. (Eds.), Capital Mobility: The Impact of Consumption, Investment and Growth. Cambridge University Press, New York. 1994: 13 – 47.) pioneered the approach of measuring consumption risk sharing by regressing individual country consumption growth on world consumption growth or world-income growth.

[26] Rangvid et al., at 9.

[27] Rangvid et al., at 3.

[28] Similar to the central learning from the Global Financial Crisis that volatility itself is volatile, we are now discovering that risk itself changes (i.e. has risks).

[29] Goetzmann, W. N., Li, L. & Rouwenhorst, K. G.: Long-Term Global Market Correlations. NBER Working Paper Series, Working Paper 8612, November 2001. p.20.

Pertinent then, is the observation that "integration today is deeper and broader than 100 years ago."[30] Risk exposures over the next decade should hence be expected to surpass risk experiences over the past ten years.

Specifically, "[market integration] is currently near an historical high – approaching levels of correlation last experienced during the Great Depression"[31]. Artis et al. documented empirically that "consumption risk sharing ha[d] increased more than commonly perceived in the literature during the 1980 – 2000 period."[32]

The implications of the non-stationarity of risk are significant:

- Risk management models, including capital and strategic risk management models that draw on past data to model future risk profiles may under-represent the severity and return periods (frequency).

- Probabilistic enterprise, capital and strategic risk models require assumptions about the stationarity of risks that depart from the reality, limiting their accuracy and the valid areas of application. Unhelpfully, their apparent levels of precision detract from the reality of their inaccuracy.

- If specific and explicit allowance for phase transitions[33] in macro-economic conditions and structural breaks[34] are not accommodated in risk models, they will materially understate future risks (in frequency, severity and nature of risks).

3. Considering Structural breaks

In addition to phase transitions, structural breaks[35] further perturb past data and their stationarity by introducing new trends and disrupting past ones. When these occur in combination with phase transitions (e.g. the introduction of smart phones following a pivot towards globalisation) the divergence from the past (and the dynamics as captured in past data) can be profound and pervasive. Moreover, structural breaks can occur in any number and combinations, and do so frequently, contemporaneously. This can impose important challenges to past data being a good fit for modelling future risks of the nature requested by the WBCSD.

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[30] Bordo, M. D., Eichengreen, B. & Kim, J.: Was There Really an Earlier Period Of International Financial Integration Comparable to today? 1998: NBER Working Paper No. W6738. Bordo, M. D., Eichengreen, B. & Irwin, D.: Is Globalization Today Really Different than Globalization a Hundred Years Ago? 1999: NBER Working Paper No. W7195. In: Forbes, K. J. & Rigobon, R.: No Contagion, Only Interdependence: Measuring Stock Market Co-Movements. 19 November 2001: p.14.

[31] Goetzmann, W. N., Li, L. & Rouwenhorst, K. G.: Long-Term Global Market Correlations. NBER Working Paper Series, Working Paper 8612, November 2001. p.20.

[32] Artis, M. J. & Hoffmann, M.: 2008. Financial Globalization, International Business Cycles and Consumption Risk Sharing. Scandinavian Journal of Economics 110: p.447 – 471. In: Rangvid et al.: p.20.

[33] For examples, refer Figures 1 and 2.

[34] Section 3.

[35] Trends / developments / innovations not observed before and for which data is sparse or non-existent.

Structural breaks include, but are not limited to:

Table 1: Examples of Future Structural breaks

Rising medical costs	Longevity	Demographic shifts	Regulation
Energy revolution	Battery storage capacity	Quantum computing	Cryptocurrencies
Technology breakthroughs	Rising inequality	Shifts in trust and truth	Brexit
Block chain	Fiscal debt levels	Quantitative Easing	Climate change
Water scarcity	Food production	Pandemics	Fusion: fake news & AI

Source: KPMG DRA CoE

Each of these structural breaks pivots the future in a direction different from the past. As such, they depart from past conditions (data). Each one therefore compromises the past data's appropriateness (fit) for predicting future exposures. When the structural breaks unfold simultaneously – as they do – the premise of past data being suitable to serve as a basis for modelling future exposures of the kind requested by the WBCSD becomes problematic.

4. Tackling the future combinations of risk

Traditional risk management tools measure the correlation of variables to determine the relationship (covariance) between them. The default for the measurement is Pearson's correlation: a bivariate correlation that measures historic, linear relationships.

The effects of phase transitions, together with any number of structural breaks, are more complicated than what bivariate, linear correlation analyses will make allowance for:

- Future risks will be shaped by many (more than two) variables contemporaneously
- The variables may affect (trigger / reinforce) each other
- The relationships between variables cannot be assumed to be linear
- One risk may affect many other risks, at the same time, with amplifying consequences
- Pearson's correlation does not measure / accommodate relationships where one variable may co-move with another but has yet to show this attribute (conditional correlation)
- Risks / variables may form feedback loops that can severely exacerbate the consequences[36] beyond what correlation can help to estimate
- Catastrophes[37] are frequently the result of many risks forming an event chain that

[36] The Piper Alpha oil rig and Chernobyl nuclear disasters.

[37] Nuclear meltdowns, aeroplane crashes, oil rigs exploding, space shuttle disasters, dam wall collapses.

may overwhelm pre-established controls / safety precautions or evolve so rapidly that they are insufficient.

5. **Risks in not recognising the non-stationarity of risks**

When risks are modelled as a distribution when, in reality, they are non-stationary, the failure of probabilistic and two-dimensional tools in risk management becomes inevitable. Examples include David Viniar from Goldman Sachs[38] who, in August 2007, stated:

> "We were seeing things that were 25-standard deviations moves, several days in a row."[39]

An 8σ event has an expected occurrence of once every 6.429×10^{12}years[40], a period "considerably longer than the entire period that has elapsed since the Big Bang."[41] A 20σ event corresponds to an expected return period measured in years that is "ten times larger than the higher of the estimates of the expected number of particles in the Universe."[42] A 25σ event equates to an occurrence frequency that is equal to the higher of the aforementioned estimate with "the decimal point moved 52 places to the left"[43,44]. And yet they seemed to have occurred "several days in a row"[45].

When founder of chaos theory Benoit Mandelbrot obtained more than a hundred years of cotton prices and futures from Harvard economist Hendrik Houtakker, he too discovered that it looked nothing like a smooth bell curve… concluding that "In fact, the bell curve fits really poorly"[46].

Mandelbrot went on to state that, if the Dow Jones did behave as if it reverted to a mean so that a distribution could be fitted to it, then it would have moved between 1916 and 2003 by more than 3.4% only on 58 days, by more than 4.5% on only 6 days and by more than 7% once in 300,000 years[47].

In reality it moved by more than 3.4% on 1,001 days, by more than 4.5% on 366 days and more than 7% on 48 days[48].

In 2012 Triana found that:

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[38] At the time.

[39] Financial Times, 13 August 2007.

[40] Dowd, K., Cotter, J., Humphrey, C. & Woods, M.: How unlucky is 25-Sigma? 24 March 2008: p. 4.

[41] According to NASA the Big Bang occurred 12 to 14 billion years ago. In: Dowd et al.: *Supra* Note 41.

[42] *Supra* Note 40.

[43] Ibid.

[44] It resembles an application of Mencken's aphorism… producing an answer that is "neat, plausible, and wrong." See also Conti-Brown, P.: A Proposed Fat-Tail Risk Metric: Disclosures, Derivatives, and the Measurement of Financial Risk. Washington University Law Review: Volume 87, Issue 6: p. 1461 – 1474.

[45] *Supra* Note 41.

[46] Mandelbrot, B. & Hudson, R.: The (Mis)Behavior of Markets: A Fractal View of Risk, Ruin and Reward. Profile Books: 2008.

[47] Ibid.

[48] Ibid.

"The normal distribution assigns a probability to extreme events that is much lower than what is observed in reality"[49].

The non-stationarity of risks resulting from the disruptive consequences of phase transitions, the pivots from the past triggered by structural breaks and the non-linear, non-bivariate but multi-variate interconnectedness between the evolving and emerging discrete risks mean that distributions should be fitted to past data for risk management purposes only with reservation and circumspection. This approach is best reserved for attributes of risk that lend itself to the type of analyses: Large quantities of data that generate relatively low value outcomes[50]. Still, the potential consequences of phase transitions, structural breaks and interconnectedness on the data should be considered with adjustments made where required[51].

In the case of the WBCSD question, the non-stationarity of change and its pertinence to future risks meant that alternative risk models[52] had to be applied.

6. **Modelling risk whilst accommodating its non-stationarity**

The model most suited, and currently most widely accepted and applied in accommodating the implications of the above is graph or network theory[53]. Networks have been used in a variety of risk management applications for decades: air traffic control, neurology, epidemiology, electrical power risk management, railways, traffic control, bio-diversity management, eco-system preservation and more[54]. The exception to this, until now, has been risk management in business (and finance).

The usefulness of networks in modelling non-stationary exposures demonstrated its relevance in January 2007 when the World Economic Forum published its global risk network – 20 months before the failure of Lehman Brothers in September 2008:

[49] Triana, P.: The Number That Killed us. Wiley: New Jersey. 2012: p. 35.

[50] E.g. motor vehicle claims modelling.

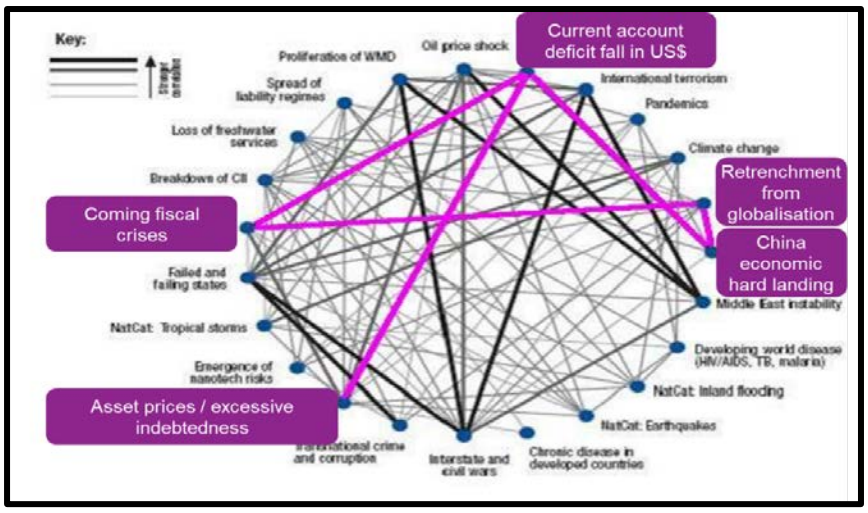
[51] E.g. how will COVID-19 impact expected motor vehicle accident frequency in countries where lockdowns have been implemented? When more people work from home and drive less?

[52] Expert Elicitation, Networks, Behavioural Finance.

[53] Examples include the World Economic Forum and the Bank of England.

[54] See examples at Appendix B.

Figure 6: World Economic Forum Global Risks Network



Source: Global Risks 2007 – A World Economic Forum Report, p. 13. (Own emphases).

Research is clear that, in circumstances where data is not available or where it constitutes a poor fit, modelling should take the form of expert elicitation[55].

When it involves an analysis of a 'systems problem' with phase transitions (Section 2) and structural breaks (Section 3 and Table 1) in which contagion propagates to individual risks within that system beyond bi-variate interactions (Section 4), networks as a means of modelling its behaviour and attributes have risen in prominence[56]. Dynamic Risk Assessment, or DRA, constitutes one such application of a network.

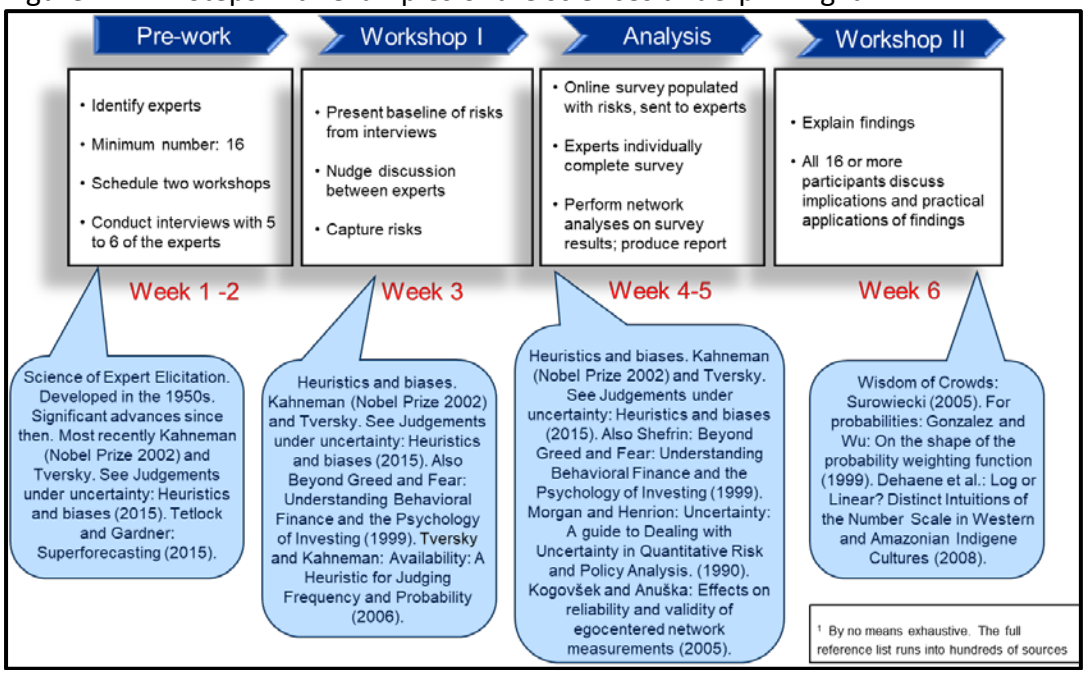
In principle DRA consists of four steps:

Expert elicitation was first used in Cold War war game modelling – as there was no past data or precedent to draw upon.
It came of age in the 1970s: in 1975 concerns were raised about super and sub-sonic air travel due to the known relationship between fossil fuel generated nitrogen and sulphur oxides and their impact on the ozone. Expert elicitation then application to the effects of chlorofluorocarbons (CFCs) used in refrigeration, fire extinguishers and as propellants in aerosol containers on the depletion of the ozone, which resulted in them being phasing out.
Two years later, in 1977, the U.S. Environmental Protection Authority (EPA) used it to re-assess the standards for airborne pollutants. This led to the commoditization of "the right to emit" and cap-and-trade market mechanisms for abatement, to become traded on the Chicago Climate Exchange (CCX).

[55] Spetzler, C.S. & Staël Von Holstein, C-A. S.: (1975) Exceptional Paper - Probability Encoding in Decision Analysis. Management Science 22(3): 340-358; Staël Von Holstein, C-A. S., Matheson, J.E.: A Manual for Encoding Probability Distributions: Final Report. Defense Advanced Research Projects Agency, 1978; Morgan, M. G. & Henrion, M.: Uncertainty. A Guide to Dealing with Uncertainty in Quantitative Risk And Policy Analysis. Cambridge University Press: Cambridge. 1990: P. 141-161; Slottje, P., Sluijs, J.P. van der & Knoll, A.B.: Expert Elicitation: Methodological suggestions for use in environmental health impact assessments. RIVM letter report: 630004001/2008. p.7

[56] Kubelec, C. & Sa, F.: The Geographical Composition of National External Balance Sheets: 1980-2005. World Economic Forum: Global Risk Report. January 2007 (See Appendix F); Bank of England Working Paper No. 384, 2010: International Journal of Central Banking. P. 143-189; Haldane, A. G.: Rethinking the Financial Network. Bank of England: 2009. Speech delivered to Financial Student Association, Amsterdam: 28 April 2009; Castells, M.: The Rise of the Network Society. Economy, Society, and Culture Wiley Blackwell: West Sussex: United Kingdom 2010; Castells, M.: Networks of Outrage and Hope. Social Movements in the Internet Age. Polity Press: Cambridge. 2012.

Figure 7: DRA Steps with examples of the sciences underpinning it



Source: KPMG DRA CoE

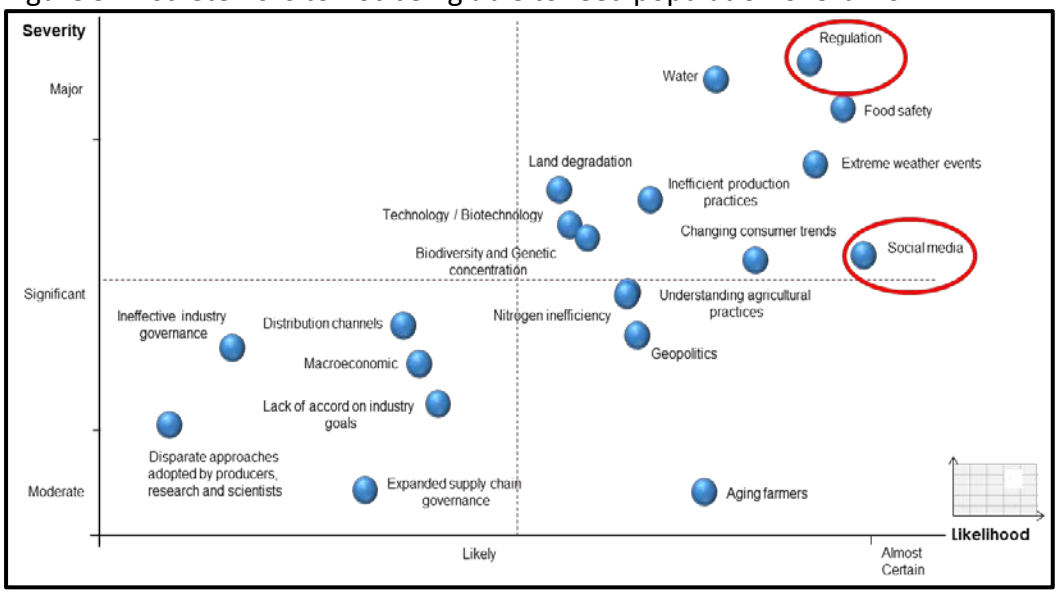
7. **Dynamic Risk Assessment of the risks**

With the methodology decided upon, the WBCSD generously arranged for the following companies to make their experts available for the DRA process:

Figure 8: Companies' experts consulted

From the application of the process (Figure 7) the following discrete risks were identified:

Figure 9: Discrete risks to not being able to feed population of 9 billion



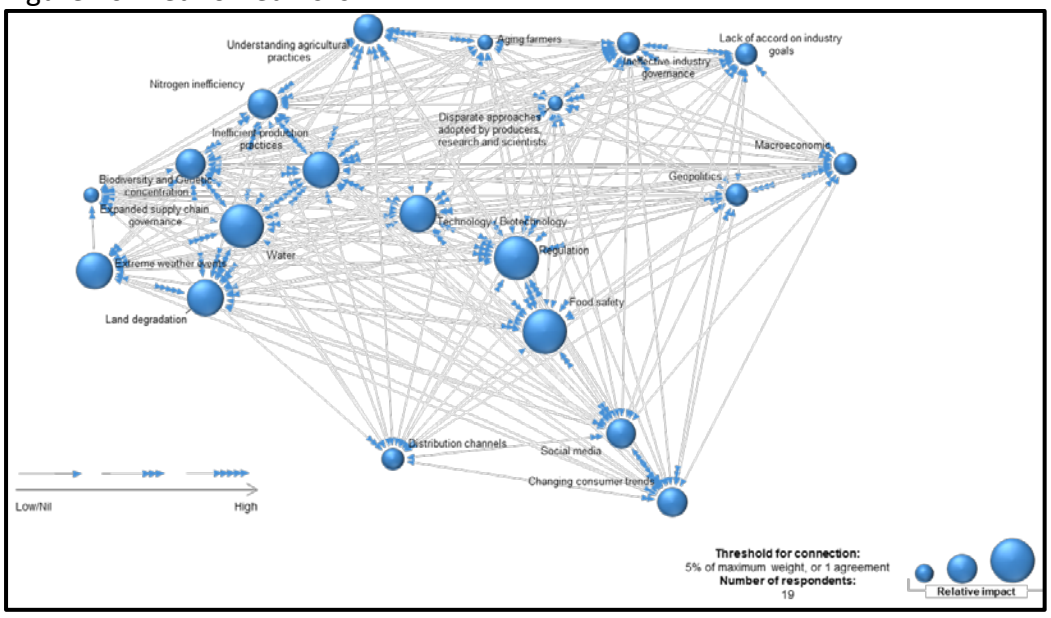
Source: DRA

Importantly, the process of identifying the risks in Figure 7 made explicit allowance for the existence of phase transitions in Section 2 and structural breaks (Section 3), whilst throughout the process adopting extensive measures – consistent with behavioural finance - to debias the outcomes.

Nevertheless, were the risk analysis to have finished here, the biggest risks to being able to feed a population of 9 billion would have been identified as Social Media (highest likelihood) and Regulation (most severe).

From Section 4 the multivariate, contemporaneous causal interactions and the existence of feedback loops between discrete risks require acknowledgement in the modelling. From the DRA process it generated the following:

Figure 10: Networked risks



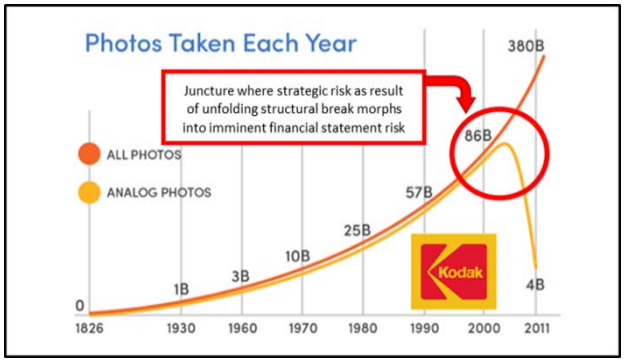
Source: KPMG DRA

It is often said that companies fail fast, or slow[57]. Applying graph theory (mathematics) to the network, the near-term risk horizon and longer-term risk horizon required consideration.

8. Near-term risk horizon

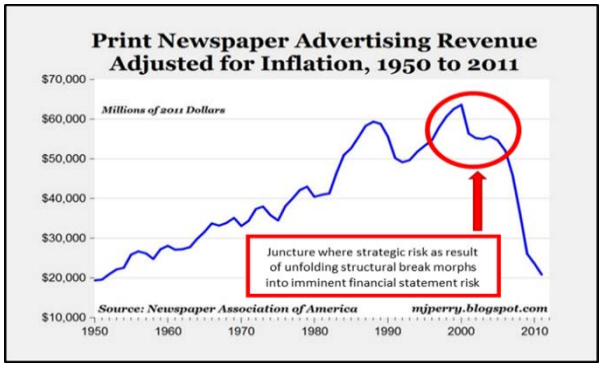
Examples of fast failures, or near-term risks abound[58]:

Figure 11: Near term impact of structural break



Source: https://singularityhub.com/2016/06/06/vital-lessons-on-disruption-from-the-demise-of-corporate-giants/ Accessed on 12.08.2017

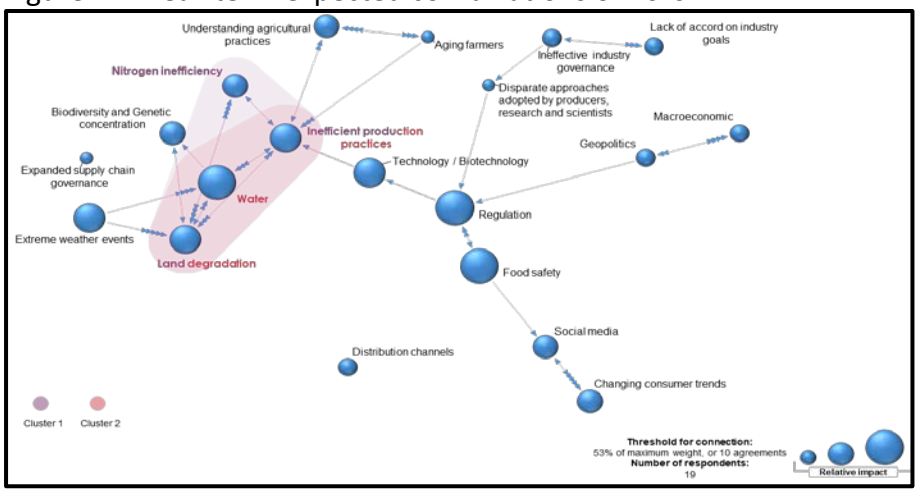
Figure 12: Print newspaper industry



Source: Derek Thompson "The Collapse of Print Advertising in 1 Graph" The Atlantic 28 February 2012

Frequently the result of a confluence of risks, graph theory was applied to isolate the combinations of risks most expected to manifest in combination with the shortest velocity[59]:

Figure 11: Near-term expected combinations of risks



Source: DRA

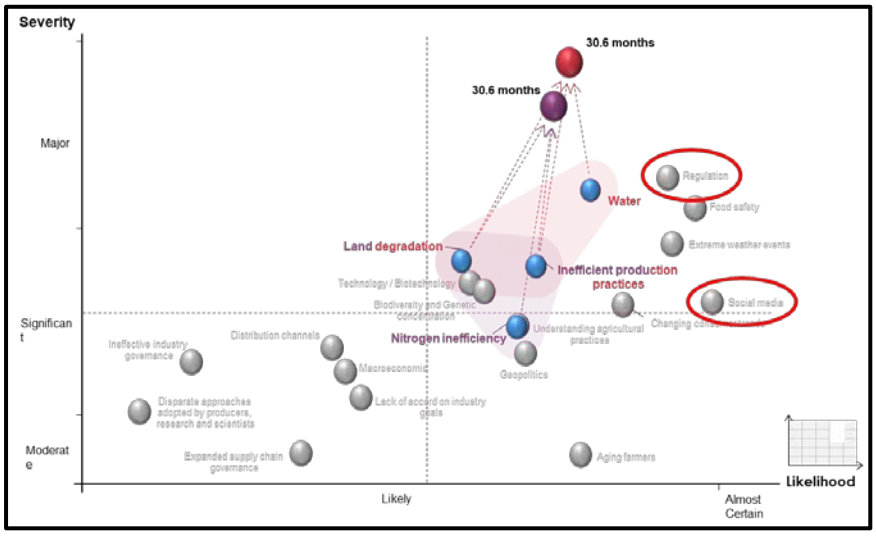
[57] E.g. Philip Twyman AM, FIAA.

[58] Examples include Encyclopaedia Britannica who started publishing in 1769 with the collective works of Aristotle, only to cease printing in 2011. At its peak in 1990 it sold 120,000 sets, six years later that number dropped to 40,000. Today it is making losses; its website has 450 million hits per annum compared to Wikipedia's 36 billion. Forty five percent of today's active researchers have never used a printed encyclopaedia; 25% of children do not know what it is. In an infamous board meeting in 1990 it celebrated record sales, global reach (on the back of the previous globalisation phase transition) and unrivalled brand strength in holding off CD rom rival Encarta. However, Wikipedia launched its website only a few weeks later. Other examples include the VHS video cassette machine that took Betamax's market share only to be usurped, suddenly, by DVD and then online streaming. Current examples include shopping centres: large numbers, pre COVID, are closing in the US as Amazon creatively destroys the traditional, 'in-shop' perusal and sales model. Only for Amazon to then buy some of the abandoned centres at fire sale prices to use as storage warehouses.

[59] Time to impact.

Two clusters (groups) of three risks, Nitrogen inefficiency, Inefficient production practices, Water and Land degradation were most expected by the experts to spread to each other if any one of them was triggered. Were this to eventuate, their aggregate expected loss[60] surpassed the discrete risk with hitherto (Figure 9) the highest severity:

Figure 12: Aggregate severity and velocity of clusters



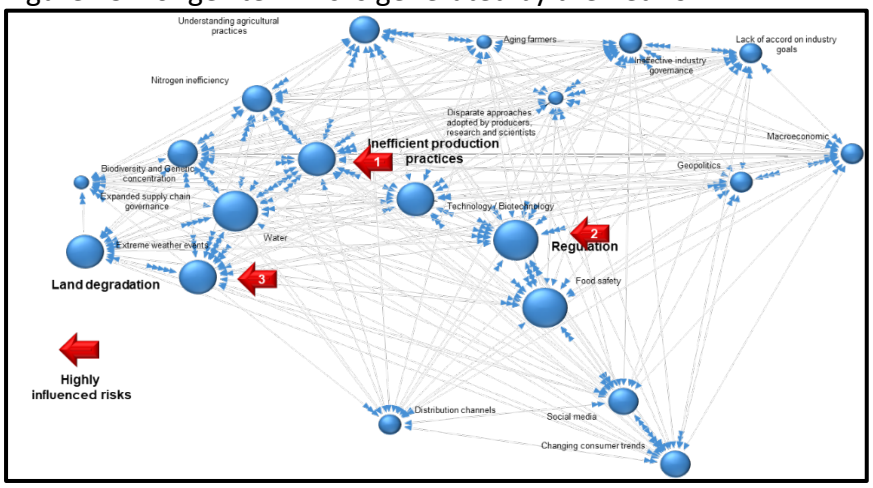
Source: KPMG DRA

The expected time to impact of the near-term risks were a mere two and a half years. The risks within these clusters can, as a system, be thought of as climate change related.

9. Longer-term risk horizon

Beyond the shorter-term risks lurk the topology-driven, systemically induced longer term risk trajectory induced by the network system. Its configuration, endowed by the experts in a debiased manner, will by its design forge certain outcomes – in this instance, systemic risks, being the longer-term risk result. Applying graph theory, the topology of the network can be analysed to determine what eventual results of its operation will yield:

Figure 13: Longer-term risks generated by the network

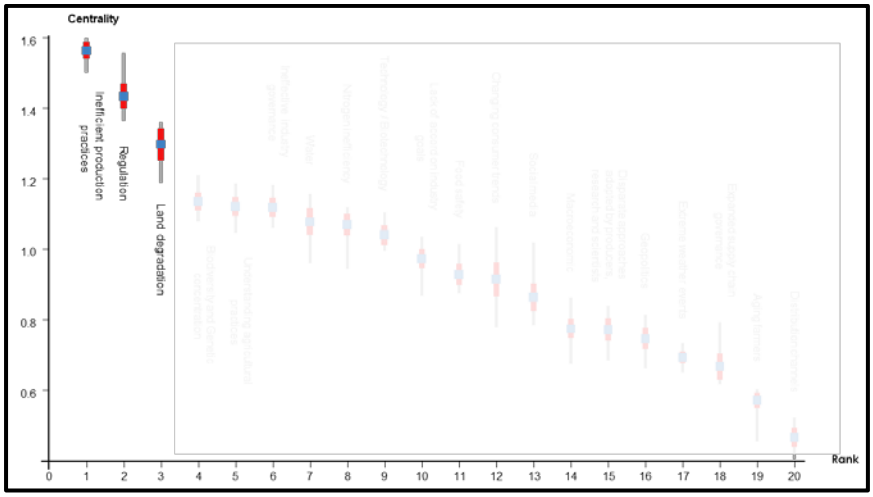


Source: KPMG DRA

[60] In terms of lower bound.

The risks in Figure 14 are those most affected, or influenced, by every other risk. As such they represent the topological destiny of the system, in rank order:

Figure 14: Rank order of being influenced / triggered by other risks



Source: KPMG DRA

Without (systemic) intervention, the risks that will prevent nine billion people from being fed in future are, in descending order of threat:

1) Inefficient production practices
2) Regulation
3) Land degradation

For ease of reference, their definitions are repeated here:

Table 2: Definitions of most threatening systemic risks

Risk description	Risk Definition
Inefficient production practices	Current production practices not using / sustaining finite resources optimally when technology to do so exists. These impact yields adversely, as it does cost and supply
Regulation	Possibility of sudden / non-science based / increased regulation being introduced. Can lead to escalating compliance costs, existing markets suddenly becoming inaccessible / rise in the number of breaches / increased costs of production
Land degradation	Poor understanding and incentivization of sustainable land and soil health practices result in potentially irreversible damage to production capacity, and escalating costs per unit of production

Source: KPMG DRA

These risks in the main, then, represent the longer term, predestined risk outcome forged by the topology of the risk architectural structure as a *complex adaptive system*.

This outcome requires an optimised *process of mitigation*[61] to alter its predestined course. In other words, a mitigation response in terms of which risks are mitigated discretely and in an unconnected manner induces the risk that it may / *will not change the overall outcome*. For

[61] Mitigating individual (discrete) components within the Complex Adaptive System on an individual basis will be suboptimal in effectiveness and wasteful in terms of system-wide relevance.

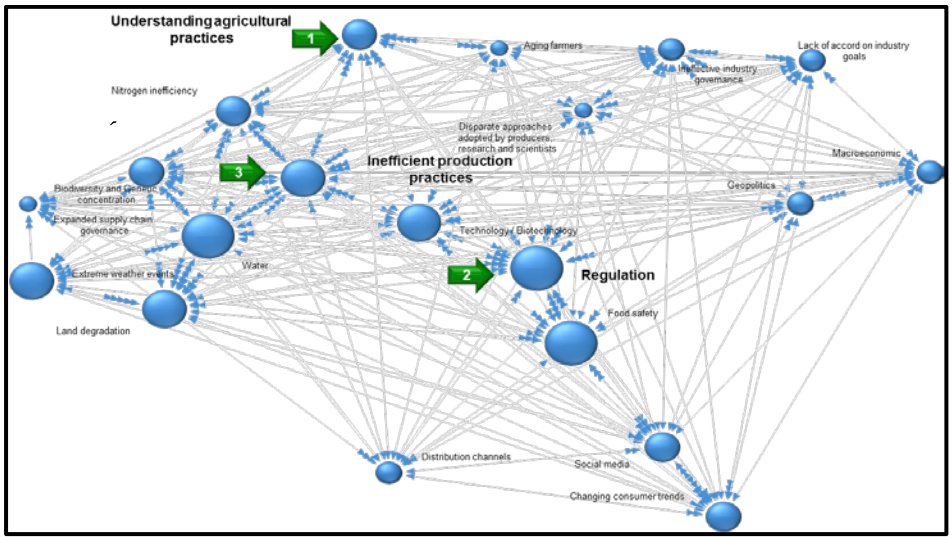
this to happen with any level of confidence, a mitigation *process / sequence of events* is required. That sequence of events was mathematically identified applying graph theory.

10. Longer-term, systemic risk mitigants

Linking the sciences of expert elicitation and networks has the added benefit of enabling the identification the most potent leverage points to mitigate the systemic network of risks.

To enable feeding a population of nine billion people the following, most influential risks in the network offer the most potent chances of changing the course of its topology:

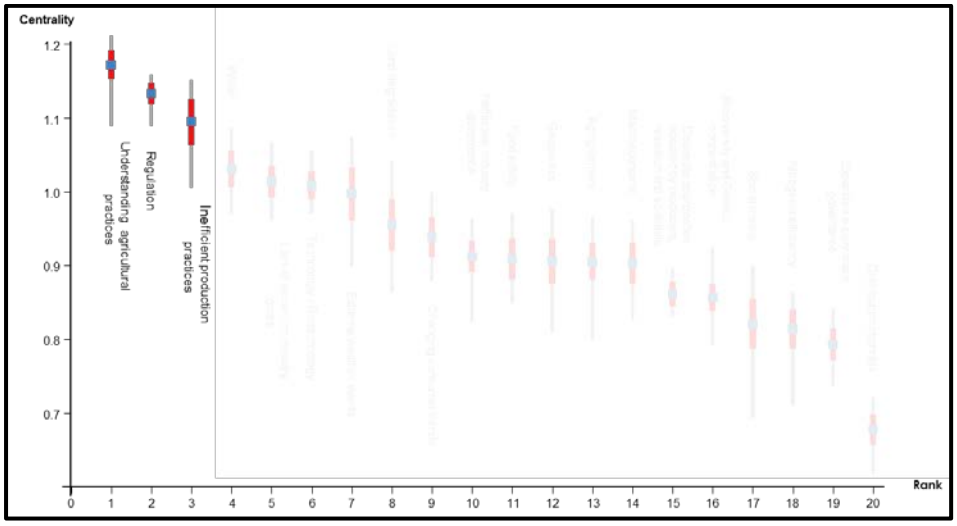
Figure 15: Most influential risks



Source: KPMG DRA

Their rank order is depicted in Figure 16:

Figure 16: Rank order of influence of systemic mitigants



Source: KPMG DRA

The definition of Understanding agricultural practices was:

Table 3: Definitions of (additional) most influential systemic risk (to be read with Table 2)

Risk description	Risk Definition
Understanding agricultural practices	Populations moving away from farming and becoming dispassionate about the criticality of farming - adopting increasingly popular, urbanised views with adverse consequences to farming. Result is more regressive practices, higher costs, lower yields and other unintended consequences

Source: KPMG DRA

The *only way* in which a population of nine billion people can be fed through the mitigation of the systemic risks that will prevent this outcome, is by focusing on Understanding agricultural practices and using this understanding to inform Regulation as well as Inefficient production practices. These three mitigants – all of them, in that order, *as a sequence of mitigation,* is what is required to change the existing systemic risk course. A discrete mitigant, e.g. focusing on Inefficient production practices only, is not sufficiently pervasive in mitigation to change the whole-of-system outcome of an entire network in producing the downside outcomes in Figures 13 and 14.

11. **Risk feedback loops**

Table 4 illustrates how the systemic mitigants in Figures 15 and 16 are expected to propagate through the complex adaptive system of the systemic risk network to form powerful feedback loops. Of interest are the loops that will optimally[62] proliferate the dispersion of mitigation[63] throughout the (complex adaptive) system[64]:

Table 4: Systemic risk feedback loops

Emitter Rank	Top Emitter Risks	Receiver Rank	Top Receiver Risks
1	Understanding agricultural practices	1	Inefficient production practices ① ②
2	Regulation	2	Regulation
3	Inefficient production practices ① ②	3	Land degradation ① ②
4	Water ②	4	Biodiversity and Genetic concentration
5	Lack of accord on industry goals	5	Understanding agricultural practices

Source: KPMG DRA

From Table 4 it can be seen that Understanding agricultural practices is more powerful to the network that what it is influenced by the network (that is, it features as #1 on the left and ('only') as #5 on the right). Being that powerful, its mitigation will optimally impact every risk more prone to being influenced by the network than in and of itself (i.e. the risks ranked higher (more systemically vulnerable) on the right. Understanding agricultural

[62] With the greatest impact on the highest number of other risks in the shortest pathways.

[63] Risks that are most influential towards other risks (that is, highly ranked on the left-hand side in Table 4) and for which the mitigation consequences spread optimally (in the shortest pathways) to the most vulnerable systemic risks (Figures 13 and 14 as well as Table 4 on the right-hand side).

[64] Risks that feature on both the left- and right-hand sides but are ranked higher on the left than they are on the right-hand side.

practices is systemically the most potent mitigant for the remediation of Biodiversity and Genetic concentration; Land degradation, Regulation and Inefficient production practices.

Regulation features as #2 on both sides. That characteristic renders it a force multiplier: it will either work to sustain the systemic mitigation of the complex adaptive system of risks, or it will pivot to work against that outcome. It offers no middle ground. The main determinant of that outcome can be found in the #1 position on the left: if regulation is introduced with an understanding of the agricultural practices, it will add momentum towards systemic mitigation of the predestined outcome in Figures 13 and 14. If not done in that manner, it will pivot to add momentum to the eventuation of that systemic risk destiny.

From Table 4 inefficient production practices is less influential towards other risks (#3 on the left) than the extent to which it is influenced by other risks (#1 on the right). It follows that the discrete mitigation of this risk is unlikely to result in a low residual outcome, as it can be triggered / exacerbated by any other risk in the network. Attempts to mitigate it in a discrete manner constitute an inefficient and ineffective approach in reducing its residual threat.

12. Summary

The macro-economic environment is characterised by phase transitions and structural breaks that result in risk being non-stationary. It rendered, for the risk question at hand, past data to be a poor fit for modelling the future risks. In these circumstances expert elicitation, in conjunction with network theory and behavioural finance offer alternatives for modelling Enterprise Risks and the question under investigation.

The study found that, unless the current (lack of) understanding of agricultural practices is addressed (mitigated), Regulation will pivot into a force driving an adverse eventual outcome.

Furthermore, Inefficient production practices is systemically more vulnerable than what it is influential, so that it cannot be mitigated to an acceptable level of residual risk as a discrete threat.

Appendix A: Predictive regressions[65]

This table shows results for predictive regressions of risk sharing on market integration (cross-sectional return dispersion of stock returns):

$$\overline{\text{Risk sharing}}_{t+h} = \alpha_h + \gamma_h \overline{\text{Market integration}}_{t+1-k} + \varepsilon_{t+h}.$$

in the left part of the table and results for the reverse regression

$$\overline{\text{Market integration}}_{t+h} = \alpha'_h + \delta_h \overline{\text{Risk sharing}}_{t+1-k} + \varepsilon'_{t+h}.$$

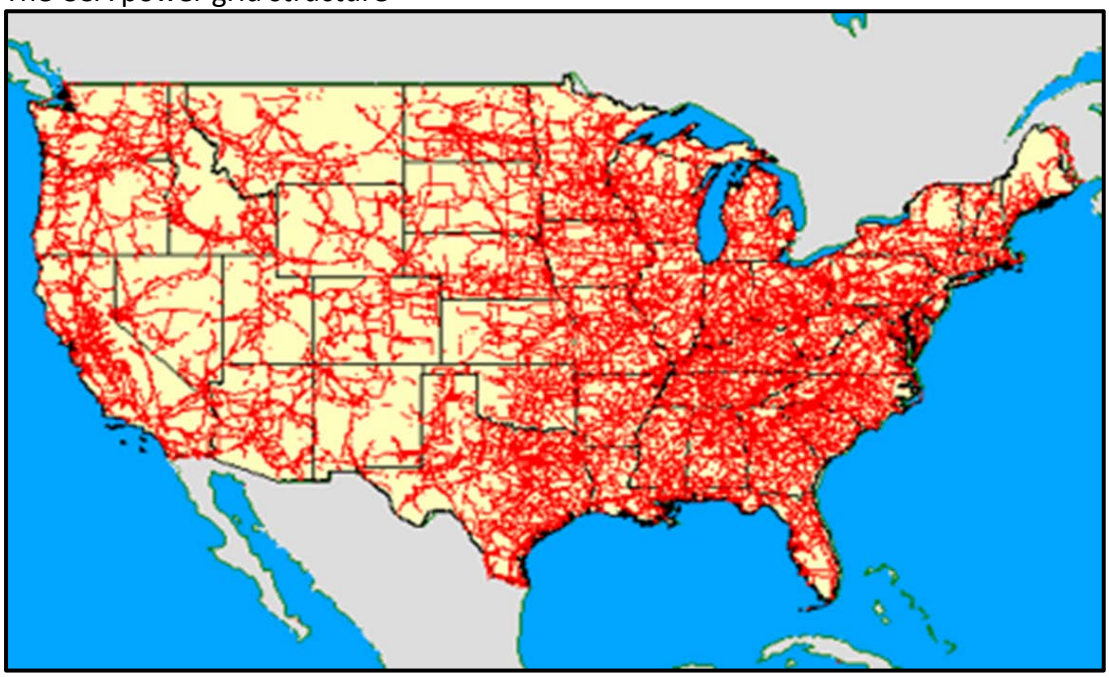
in the right part of the table. The forecast horizon ranges from $h = 1, 3, 5$ to $h = 10$ years and we use lagged moving averages of financial market integration measures (or risk sharing measures) over the last $k = 1, 2, 5, 10$ years to forecast future averages of the consumption risk sharing (or financial market integration) measure. We report the slope coefficients γ_h of the predictive regressions, t-statistics based on Newey and West (1987) standard errors (t_{NW}), Hodrick (1992) standard errors (t_H), and predictive R^2s.

	Dependent: Risk Sharing						Dependent: Market Integration				
		Forecast horizon h in years						Forecast horizon h in years			
k		1	3	5	10	k		1	3	5	10
1	γ_h	0.13	0.31	0.69	1.36	1	δ_h	0.14	0.11	-0.17	-0.21
	t_{NW}	[1.43]	[1.26]	[1.90]	[2.65]		t_{NW}	[1.71]	[0.39]	[-0.31]	[-0.19]
	t_H	[1.46]	[1.51]	[2.11]	[2.60]		t_H	[1.65]	[0.60]	[-0.65]	[-0.55]
	R^2	0.02	0.02	0.06	0.10		R^2	0.02	0.00	0.00	0.00
2	γ_h	0.13	0.40	0.82	1.59	2	δ_h	0.08	-0.01	-0.33	-0.31
	t_{NW}	[1.26]	[1.53]	[2.08]	[2.83]		t_{NW}	[0.76]	[-0.04]	[-0.46]	[-0.21]
	t_H	[1.35]	[1.76]	[2.23]	[2.65]		t_H	[0.87]	[-0.07]	[-1.02]	[-0.62]
	R^2	0.02	0.04	0.09	0.14		R^2	0.01	0.00	0.01	0.00
5	γ_h	0.19	0.64	1.18	1.93	5	δ_h	-0.02	-0.24	-0.48	-0.38
	t_{NW}	[2.00]	[2.42]	[2.86]	[2.94]		t_{NW}	[-0.18]	[-0.47]	[-0.51]	[-0.20]
	t_H	[2.05]	[2.45]	[2.95]	[2.84]		t_H	[-0.23]	[-0.88]	[-1.18]	[-0.59]
	R^2	0.04	0.10	0.18	0.21		R^2	0.00	0.01	0.02	0.00
10	γ_h	0.27	0.78	1.28	2.08	10	δ_h	-0.03	-0.12	-0.20	-0.06
	t_{NW}	[2.96]	[3.07]	[2.93]	[2.74]		t_{NW}	[-0.26]	[-0.24]	[-0.23]	[-0.03]
	t_H	[2.94]	[3.03]	[3.07]	[2.96]		t_H	[-0.35]	[-0.42]	[-0.46]	[-0.08]
	R^2	0.07	0.15	0.20	0.24		R^2	0.00	0.00	0.00	0.00

[65] Rangvid et al.: p.34. Also: Newey, W.K. & west, K.D.: A Simple, Positive semi-definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix. *Econometrica* 55, 1987: 703 – 708; Hodrick, R.: Dividend Yields and Expected Stock Returns: alternative Procedures for Inference and Measurement. *Review of Financial Studies* 5, 1992: 357 – 386.

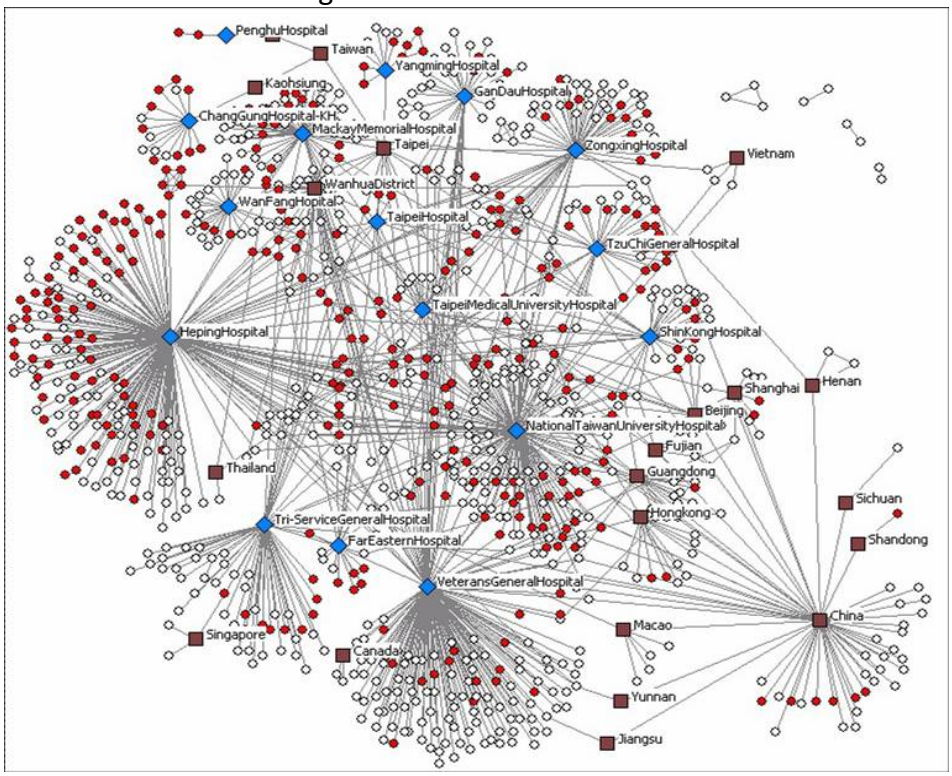
Appendix B: Examples of Networks

The USA power grid structure



Source: Google Images: https://www.google.com.au/search?client=safari&hl=en-gb&biw=1024&bih=672&tbm=isch&sa=1&ei=2CCQUeXBLMjslAXA2YGwAw&q=powergrid+network&oq=powergrid+network&gs_l=img.3...31823.41948.0.42674.36.33.0.1.1.6.441.4973.12j6j11j1j1.31.0...0.0...1c.1.12.img.c2nUuhAZdx4#biv=i%7C3%3Bd%7CSpTf8UoPjrNQ2M%3A

SARS Breakout Modelling



Source: Goggle Images: https://www.google.com.au/search?client=safari&hl=en-gb&biw=1024&bih=672&tbm=isch&sa=1&ei=MSCQUd7LLoLElAXzsoDQBw&q=Sars+virus+network&oq=Sars+virus+network&g

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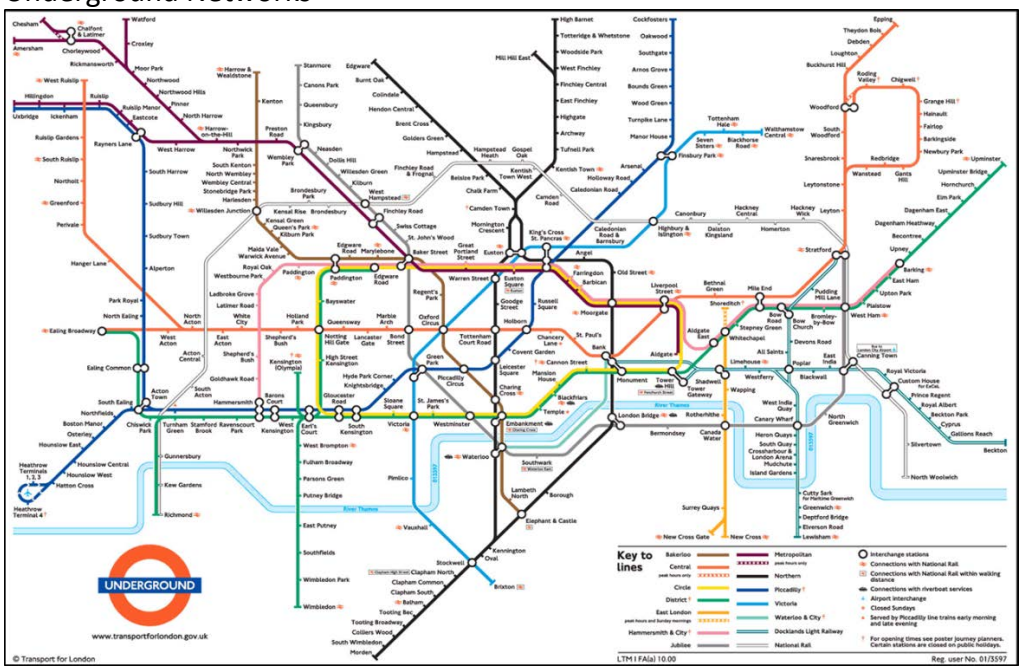
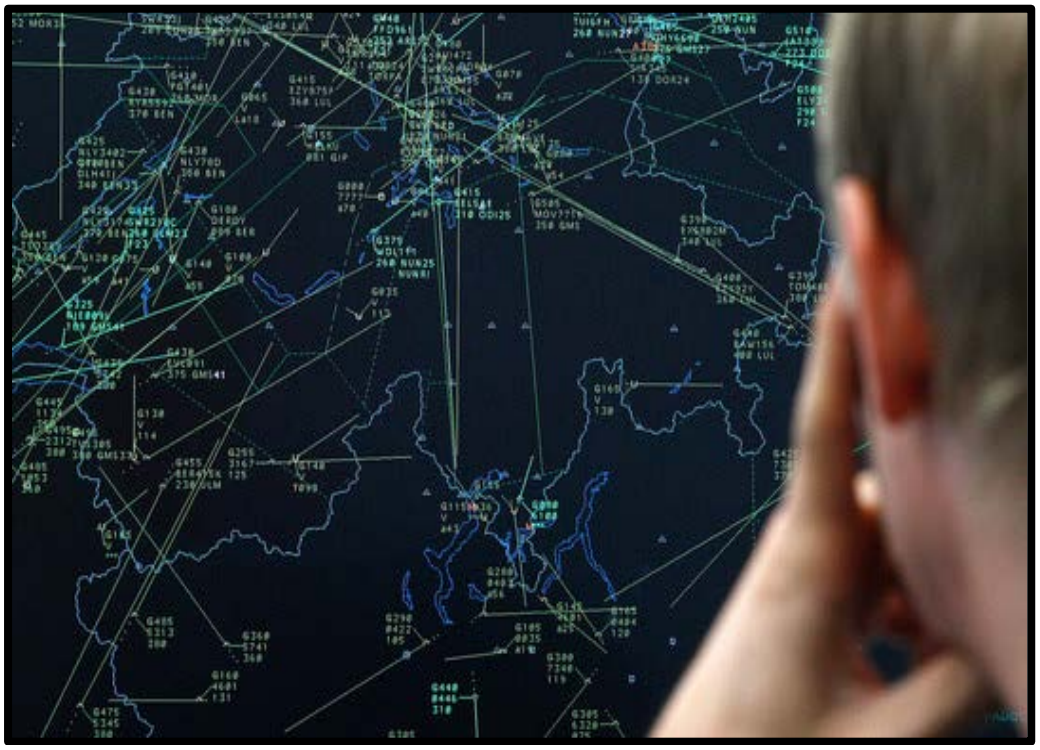
Underground Networks



Air Traffic Control



Source: The Economist Online. 16 March 2013

COVID-19 Pandemic Contagion Pathways

Appendix C: About the Authors

Andries Terblanche is a Fellow of the Institute of Chartered Accountants in Australia, a member of the Institute of Chartered Accountants of New Zealand and a member of the South African Institute of Chartered Accountants. He holds Fellowships with the Australian Institute of Company Directors, the Financial Services Institute of Australia, and the Australia and New Zealand Institute of Insurance and Finance.

He currently serves as KPMG's Global Head of Systemic Risk and the Centre of Excellence for Dynamic Risk Assessment, which is based in London.

Andries studied Financial Analysis, Global Quantitative Finance and Risk Management at post graduate levels at Tsinghua University, the Hong Kong University of Science and Technology, the London School of Economics and New York University's Stern School of Business. He passed each of these with distinction, topping the classes in Financial Analysis and in Risk Management. Andries also holds a doctorate in the visual communication of complex quantitative analyses, for which he received academic colours. In addition, he has recently completed studies in behavioural finance at NYU Stern and Hong Kong University of Science and Technology and in systems thinking at Cornell University.

Until 2016, when he relocated to London, he served as Adjunct Professor in Risk and Actuarial Studies at the University of New South Wales where he taught systemic risk management to undergraduate and post graduate actuarial students as well as MBA students. Before that he was a guest lecturer on systemic risk to MBA students at the University of Technology in Sydney and an honorary professor in Financial Management.

In 2015 Andries was nominated by Prof Menachem Brenner, professor in advanced derivatives at New York University's Stern School of Business and inventor of the VIX volatility (or "fear") index, to become a member of the international honors society Beta Gamma Sigma in recognition of his academic achievements and the significance of his contributions to business. In 2016 he was appointed (with, amongst others, Nobel Prize laureates) as a Senior Research Fellow to the Global Institute of Finance.

Andries has spent the past 14 years researching why traditional risk methodologies have failed to detect the 19 globally significant economic crises post 1970 and why 147 banks since that time have collapsed without prior risk management warning. His investigation into the root causes led him to create Dynamic Risk Assessment, an automated network generation tool that accommodates the existence of structural breaks, non-stationarity characteristics of risks, phase transitions, behavioural finance, chaos theory and a paucity of data.

In January 2020 he was invited to speak in Davos at the World Economic Forum on the risks of not being able to feed a projected population of nine billion people using Dynamic Risk Assessment modelling.

Appendix D: About the Authors – Mike Ashley

Mike is the Chief Risk Scientist of the Dynamic Risk Assessment Global Centre of Excellence and in charge of research and development. He also carries responsibility for bespoke client delivery work.

Mike joined KPMG Advisory in June 2013 as a subject matter expert in quantitative financial modelling of derivatives and capital. Experienced in the modelling of derivatives across credit, FX, IR and Equities and Energy, Mike developed risk appetite, stress testing, regulatory/economic Basel II capital models and methodologies for financial institutions. In addition, he provided post-modelling support interactions with the Australian Prudential Regulatory Authority.

Prior to joining KPMG Mike worked for Macquarie Group, providing model validation for exotic derivative and capital models. In parallel Mike developed Basel II Advanced Model Approach compliant production model systems for Operational Risk and Advanced Internal Ratings Based approach models for Credit capital. This led to extensive experience with low data / high impact modelling and expert elicitation methods.

Prior to joining finance, Mike held post-doctoral positions in USA and Australia, having won research grants to analyse tera-byte-scale datasets for the detection of gravitational waves in the LIGO Scientific Collaboration. Nobel Prizes were recently awarded to its three principal investigators.

Mike holds a PhD in Mathematical Physics (ANU) and a BSc (Hons) in Theoretical Physics (ANU). He was a University Medalist and a former recipient of the Fulbright Postgraduate Award Scholarship, Australian Postgraduate Award Scholarship, and an ANU's National Undergraduate Scholarship.

Appendix E: About the Authors – Timothy Lam

Tim Lam is an actuary within the Dynamic Risk Assessment Global Centre of Excellence, in charge of technical delivery of DRA engagements. Tim is also responsible for technical development and the application of DRA across industries.

Tim joined KPMG as a graduate in 2016. He has over four years' experience in the insurance and financial services sector with specialization in pricing and valuation. In addition, he has experience in retail and group lump sum and disability income products.

Notable previous actuarial engagements include the delivery of the ADI-2014-2018 standard table for Retail Disability Income products.

Tim is currently graduating the ALS-2014-2018 for Retail Lump Sum products.